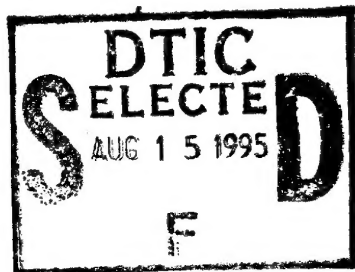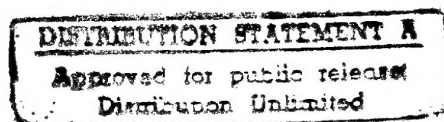# FhG

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Analysis of Energy Distribution in a Ceramic/GRP Composite

E. Straßburger and H. Senf

Final Report

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Analysis of Energy Distribution in a Ceramic/GRP Composite

E. Straßburger and H. Senf

Final Report

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Abstract

Ceramic/GRP composite targets were impacted by hemispherically nosed tungsten alloy projectiles (L = 55 mm, D = 17 mm, m = 214 g) at velocities of about 1000 m/s. The impact velocities were chosen close to the ballistic limit of this projectile-target combination which was determined from parametric tests conducted by the U.S. Army Research Laboratory, Aberdeen Proving Ground, Maryland, USA. The GRP (Glass Reinforced Plastic) laminates were S-2 Glass/Polyester fabricated by Simula Incorporated of Phoenix, Arizona, USA. Simula also glued the ceramic tiles to the S-2 glass using standard assembly techniques to maintain a consistent bond-interface thickness. The ceramic used in these tests was sintered AD995 Al_2O_3 ceramics which is nominally 99.5 % pure, produced by Coors Ceramic of Golden, Colorado, USA, under the tradename "CAP-3". The tiles of the dimensions 152 mm x 152 mm and 40 mm thickness were confined in a steel frame and glued to the GRP panels of 40 mm thickness and sizes of either 12" x 12" or 24" x 24" square. The dynamic bulging of the GRP panels during penetration was observed by means of two Cranz-Schardin high-speed cameras in side view and top view simultaneously. Distance-time curves of the bulging of the GRP panels are derived from the camera recordings for both panel sizes, and the damage of the targets is described.

Key words:

Ceramic/GRP composites, ballistic limit, high-speed photography, dynamic bulging, laminate targets, delamination

Table of Contents

1 Introduction

Modern armour components usually consist of several layers of various materials with different functions. The backing layer at the rear has to support the front layers and to defeat the residual projectile and fragments generated during penetration. In order to fulfill these requirements the backing material must exhibit not only a high strength but also a sufficient stiffness. Appropriate non-metallic materials for this purpose are for example fiberglass reinforced plastics (GRP). It is not only necessary to know if the projectile is stopped but also how much the armor is bulged during impact in order to guarantee the protection of the crew of an armored vehicle or the electronic equipment behind the armor. Since there is only very little data available on the ballistic performance GRP and composites with a GRP layer it was of great interest to generate a set of data on the kinetics of ceramic/GRP targets under impact. Particularly the influence of the size of the backing GRP panels on the performance of the targets was investigated in this study.

2 Experimental Program and Results

Four 12" x 12" x 1.5" GRP (Glass Reinforced Plastics) panels with a 152 mm x 152 mm x 40 mm aluminumoxide tile attached and three 24" x 24" x 1.5" GRP panels with 152 mm x 152 mm x 40 mm alumina tiles attached to each were delivered to EMI for ballistic testing. The GRP laminates were S-2 Glass/Polyester fabricated by Simula Incorporated of Phoenix, Arizona, USA. Simula also glued the ceramic tiles to the S-2 glass using standard assembly techniques to maintain a consistent bond-interface thickness. The ceramic tiles were confined by a steel frame of 23 mm thickness. The thickness of the epoxy joint between the tiles and the confinement was approximately 2 to 3 mm. During the tests the Ceramic/GRP panels were fixed to a steel frame by screws.

In all experiments the 55 W hemispherically nosed tungsten alloy penetrator was used. The length of the projectile is 55 mm, the diameter 17 mm and the mass is 214 g. The impact velocities were chosen close to the ballistic limit, which was expected to be 1076 m/s. The ballistic limit velocity was determined from parametric tests conducted by the U.S. Army Research Laboratory, Aberdeen Proving Ground, Maryland, USA.

A schematic of the experimental configuration is shown in Figure 2.1. The bulging of the GRP panels was observed by means of two Cranz-Schardin cameras in side view and top view simultaneously. In order to determine the yaw one free flight photograph was taken of each projectile at a distance of about 50 cm to the target. Table 2.1 provides the experimental data of all the tests.
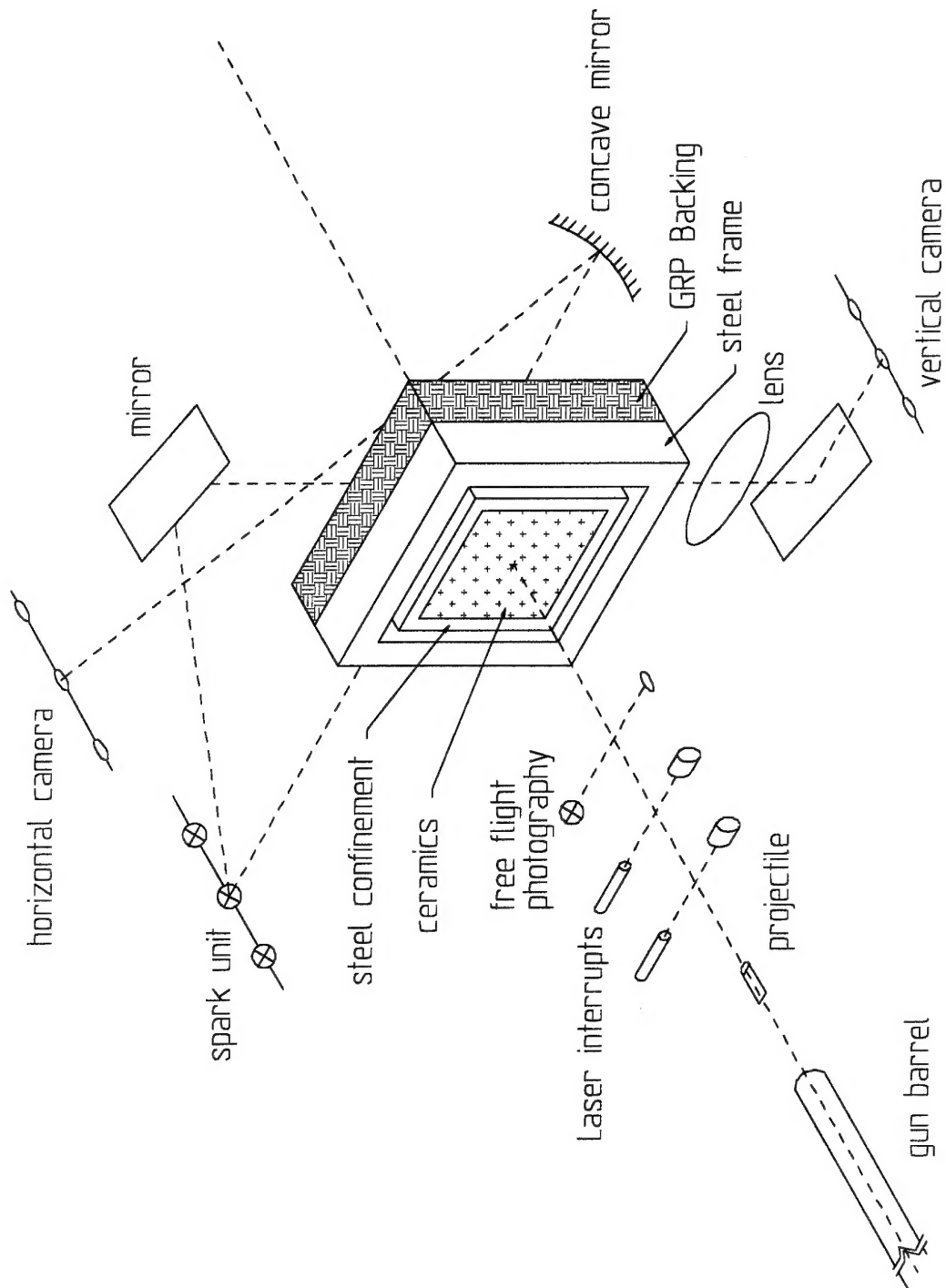
Figure 2.1   Schematic of the experimental configuration

Table 2.1   Experimental data

Shot No.	v_P [m/s]	Target	Yaw
10968	1007	Cer/GRP 24"x24"	0
10997	994	Cer/GRP 24"x24"	2
11000	1091	Cer/GRP 24"x24"	0
10973	991	Cer/GRP 12"x12"	2.3
10994	959	Cer/GRP 12"x12"	4.4
10998	1001	Cer/GRP 12"x12"	3.4
10999	997	Cer/GRP 12"x12"	---

Shot No. 10968

In order to be able to observe the beginning of the bulging the heads of the screws which fixed the GRP panel to the steel frame were countersunk into the GRP. Figure 2.2 shows the complete series of shadowgraphs from the horizontal and the vertical camera. The time intervals were 20 μs between the photographs 1 to 15 and 50 μs between the last 5 photographs. The corresponding distance-time plots of the bulge at the rear side of the GRP panel are shown in Figure 2.3.

The average velocity of the rear of the panel rises up to about 250 m/s and decreases to a few m/s during the first 300 μs after impact. The maximum height of the bulge is 35 mm during the time of observation. A static bulge of 15 mm height remained. Photographs of the target (Figure 2.4) show a delamination in the rear half of the GRP panel. This delamination could possibly be caused by the countersinking of the screws, so that the layers in the rear part of the panel were not pressed together and to the steel frame.
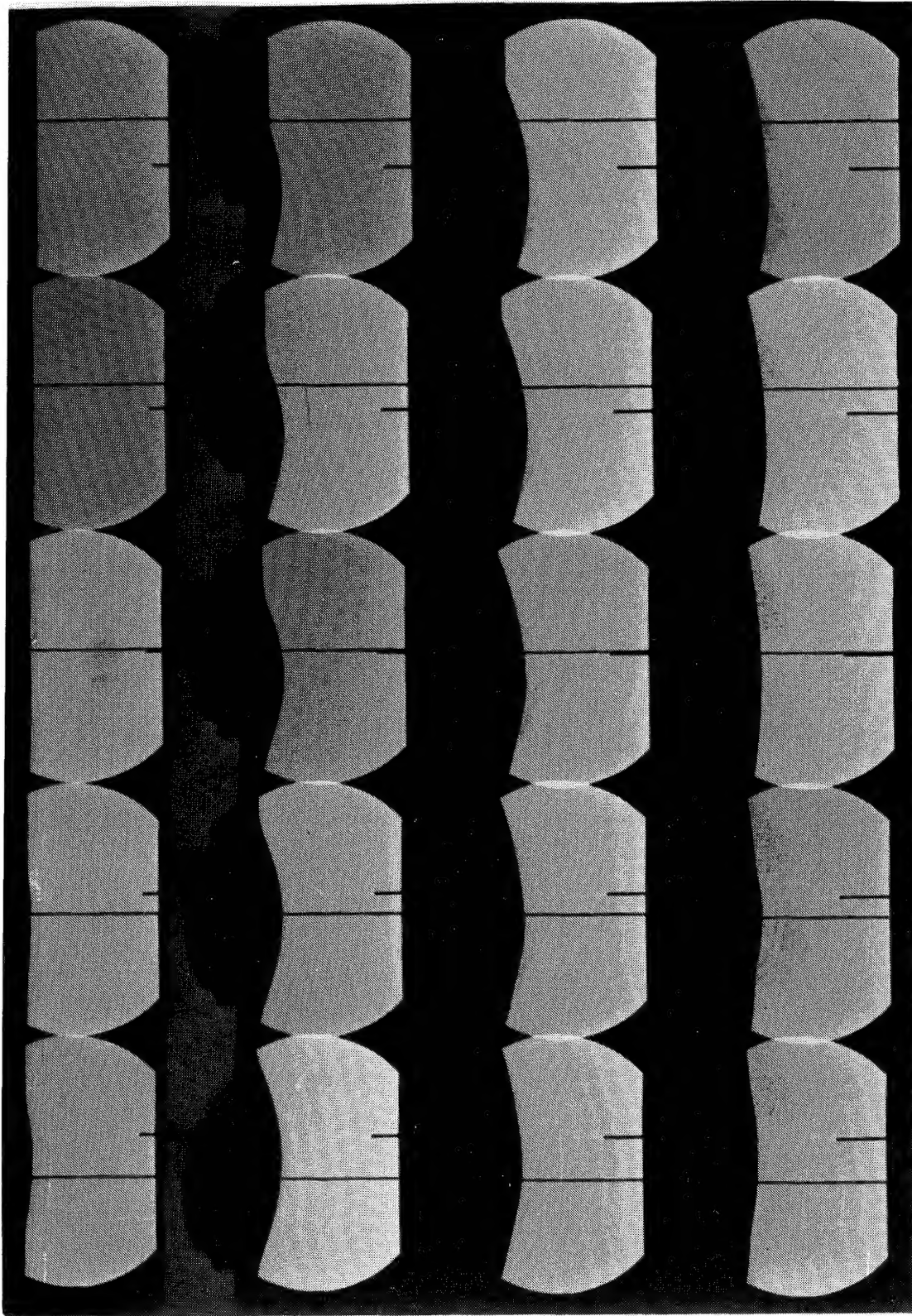
Figure 2.2   Shadowgraphs of Shot No. 10968, side view, v_P = 1007 m/s,
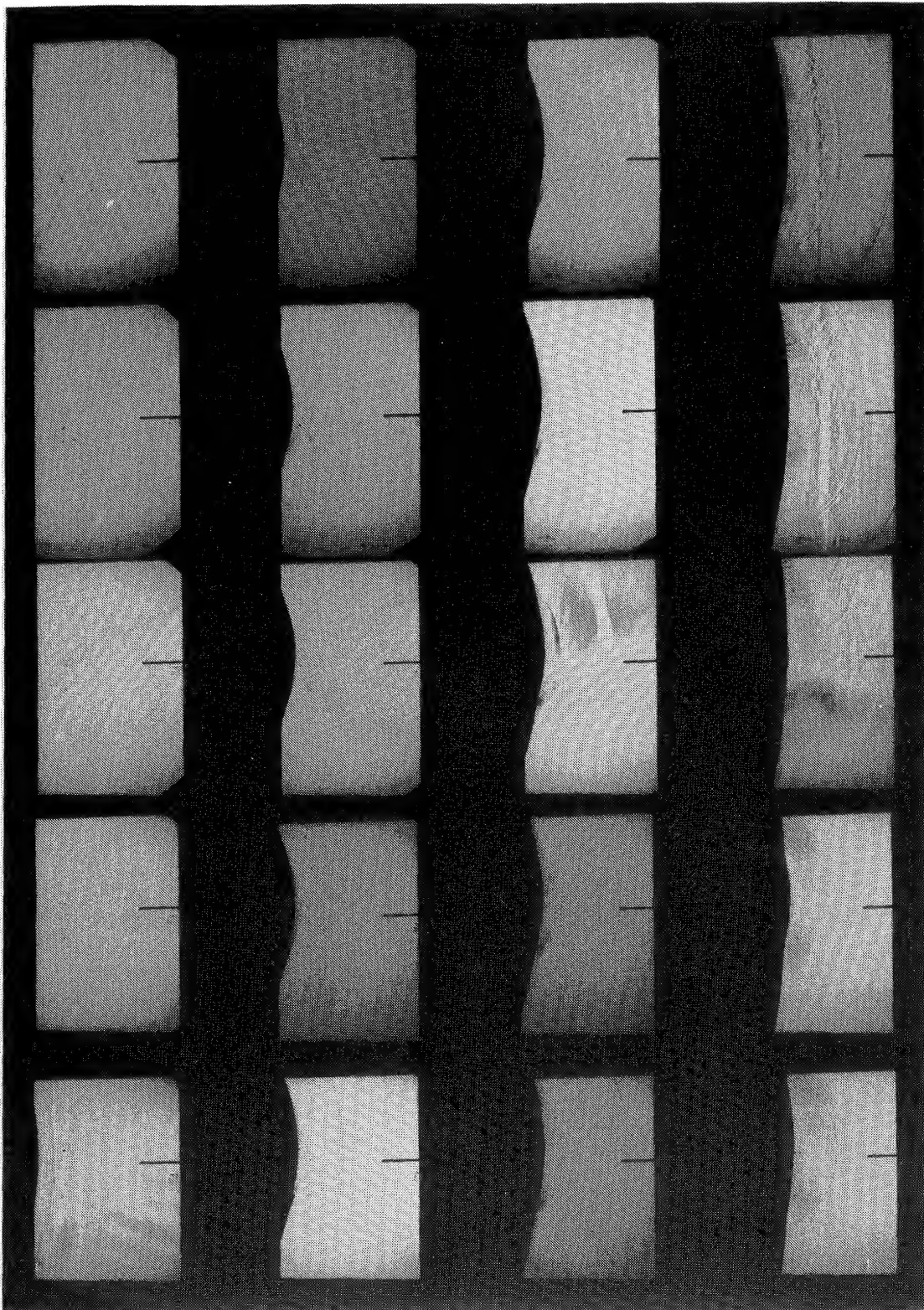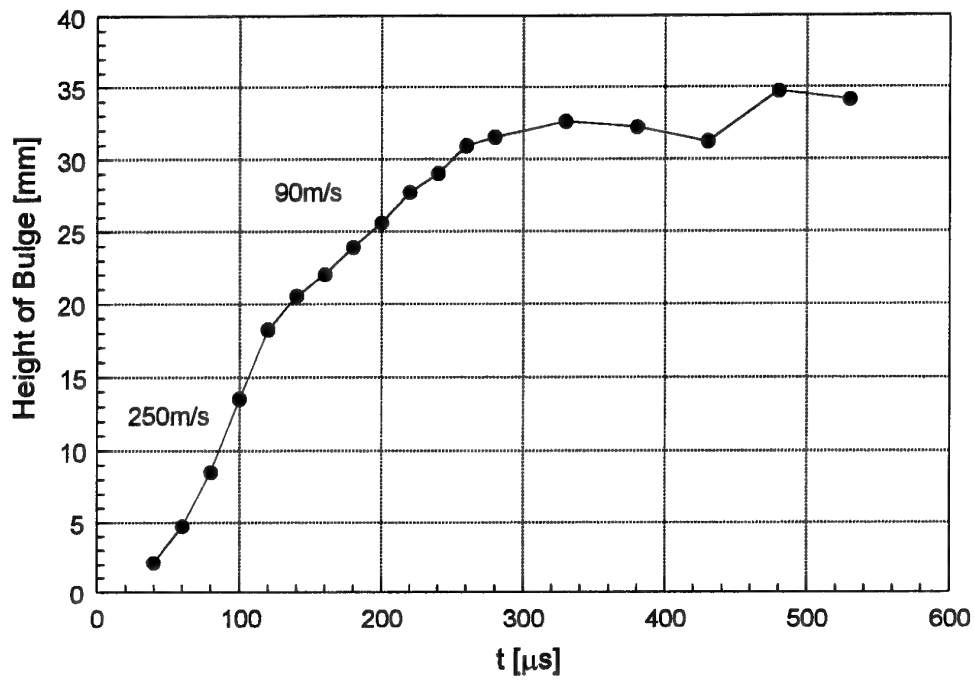Cer/GRP 24" x 24", total time 530 μs

Figure 2.2   Shadowgraphs of Shot No. 10968, top view

Horizontal Camera
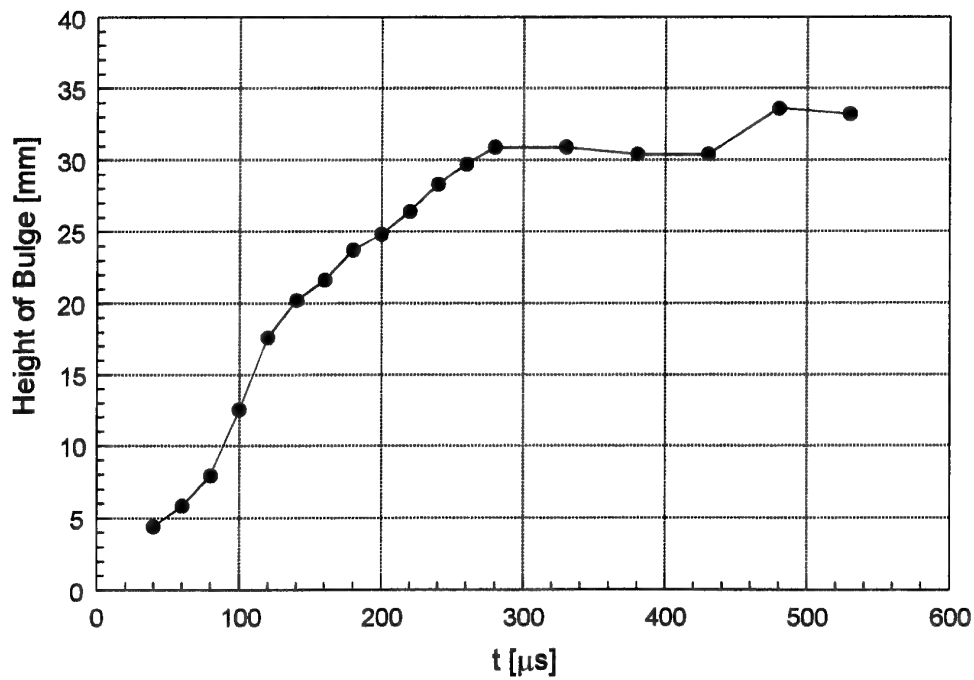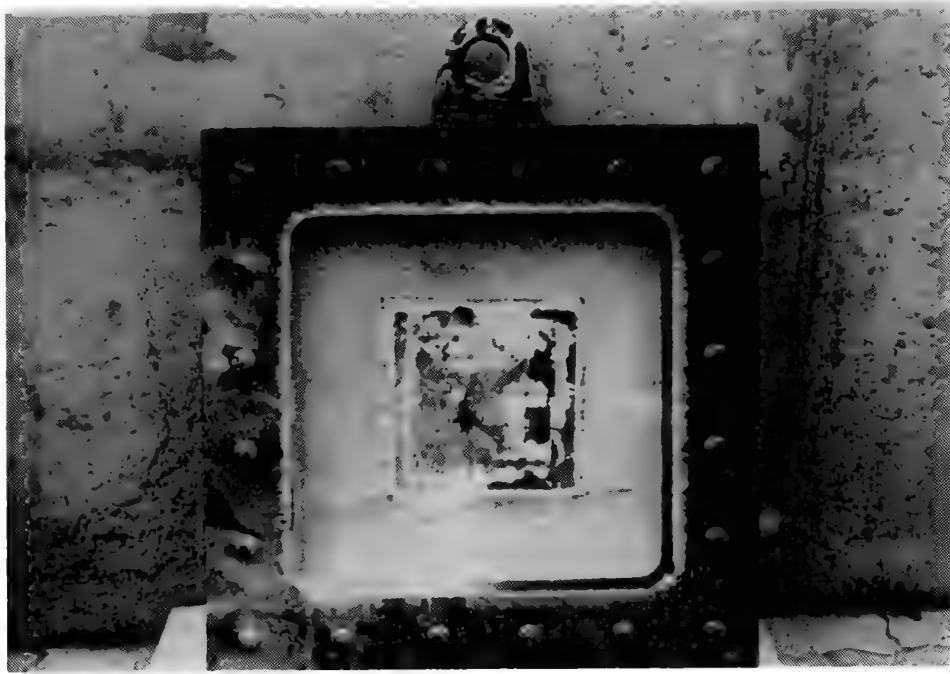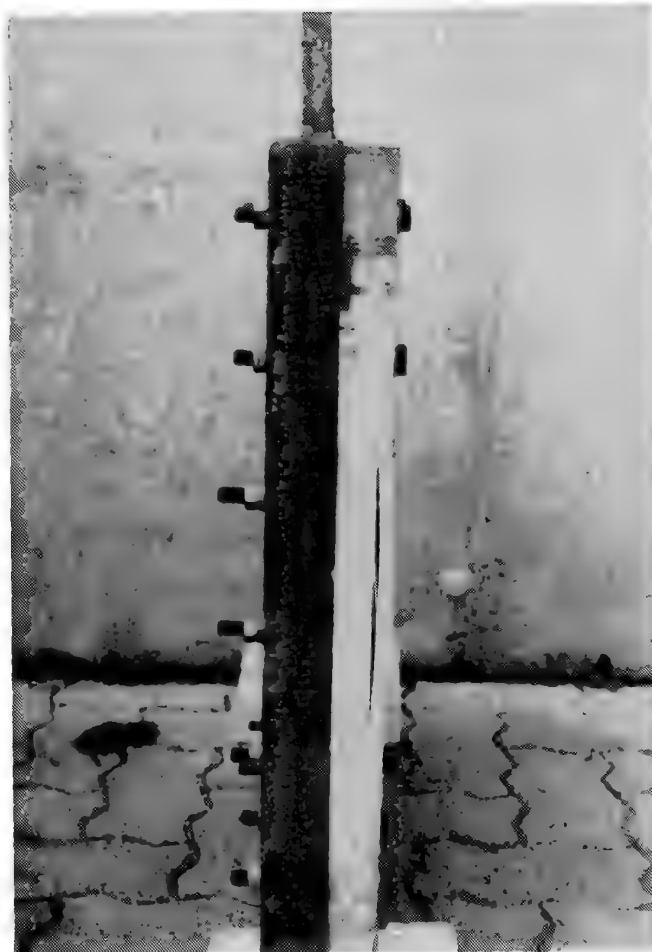

Vertical Camera

Figure 2.3   Distance-time curves of Shot No. 10968

a)   Impacted side

b)   Side view, showing the delamination

Figure 2.4   Photographs of the impacted target, Shot No. 10968

Shot No. 10997

In this experiment the GRP panel was clamped to the steel frame in full thickness and bigger washers than in Shot No. 10968 were used. Furthermore, the total time of observation was extended to 1.95 ms. The time intervals between the photographs 1 to 10 were 50 μs, 100 μs between photographs 10 to 15, and 200 μs between the last frames. The series of shadowgraphs are shown in Figure 2.5, the corresponding distance-time plots are provided in Figure 2.6.

The distance-time histories of this shot and Shot No. 10968 are well matched. The bulge reaches its maximum height of 35 mm between 300 μs and 400 μs after impact which is also in agreement with the first shot. Between 600 μs and 700 μs after impact the bulge begins to decrease. A displacement of 27 mm of the rear of the panel is observed after 1950 μs. The static bulge that remains has a height of 15 mm. No delamination of the GRP panel is visible from outside which is illustrated by the photographs of the target shown in Figure 2.7. The residual projectile has a mass of 47.7 g and a length of 15 mm.

Shot No. 11000

The first two tests of the 24" x 24" GRP panels yielded a complete path-time history of the bulging process with no failure of the target. Therefore, it was decided to perform the third experiment at a higher impact velocity in order to test the potential protective strength of this target. Figure 2.8 shows the series of shadowgraphs. The time intervals between the photographs were 50 μs. The corresponding distance-time plot derived from the recording of the vertical camera is shown in Figure 2.9. The shadowgraphs reveal that the projectile perforates the target between 200 μs and 250 μs after impact. The debris cloud that expands from the rear of the target covers the residual projectile so that the residual velocity could not be measured in this photographic arrangement. Figure 2.10 shows photographs of the target.
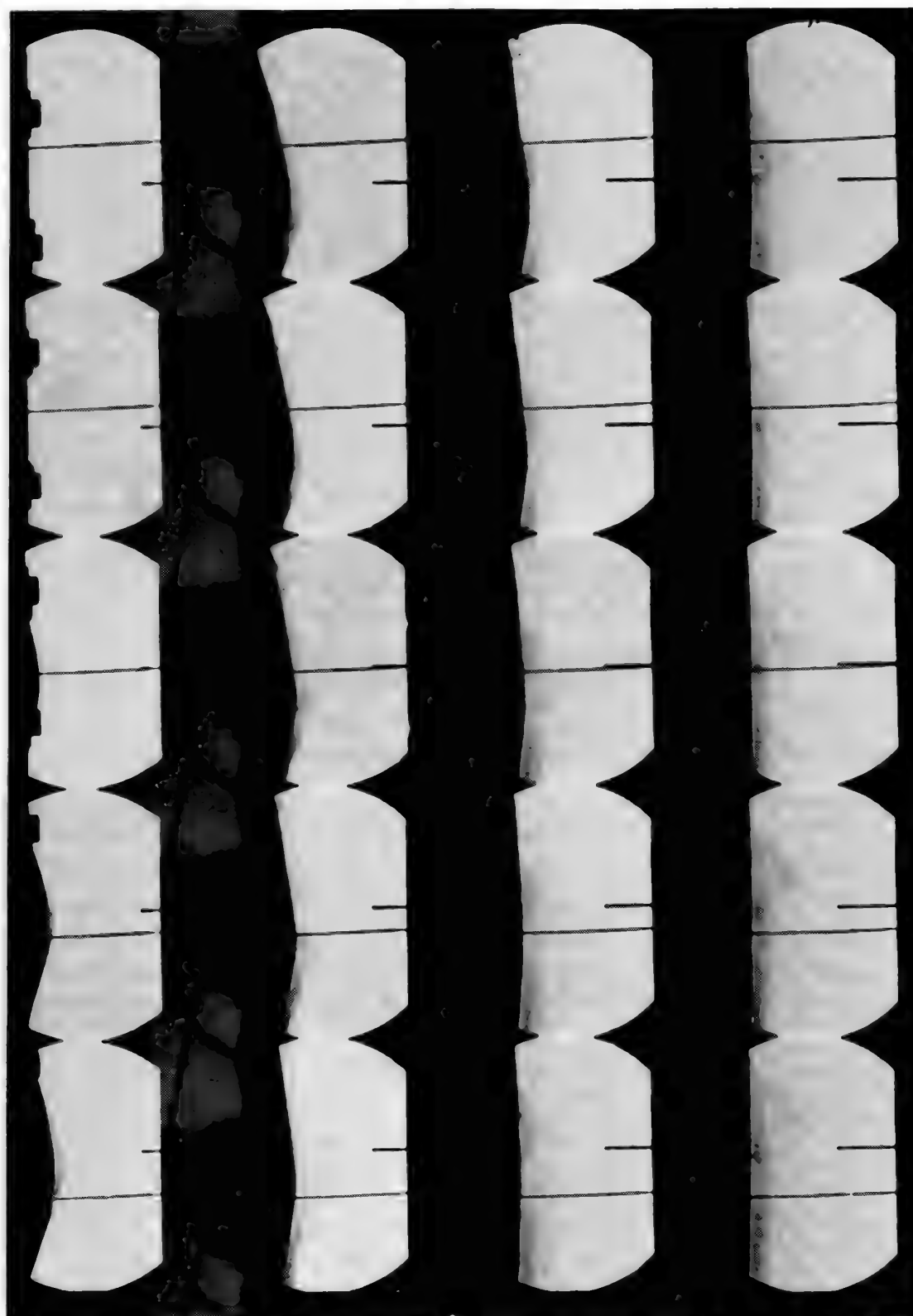
Figure 2.5   Shadowgraphs of Shot No. 10997, side view, v_P = 994 m/s,
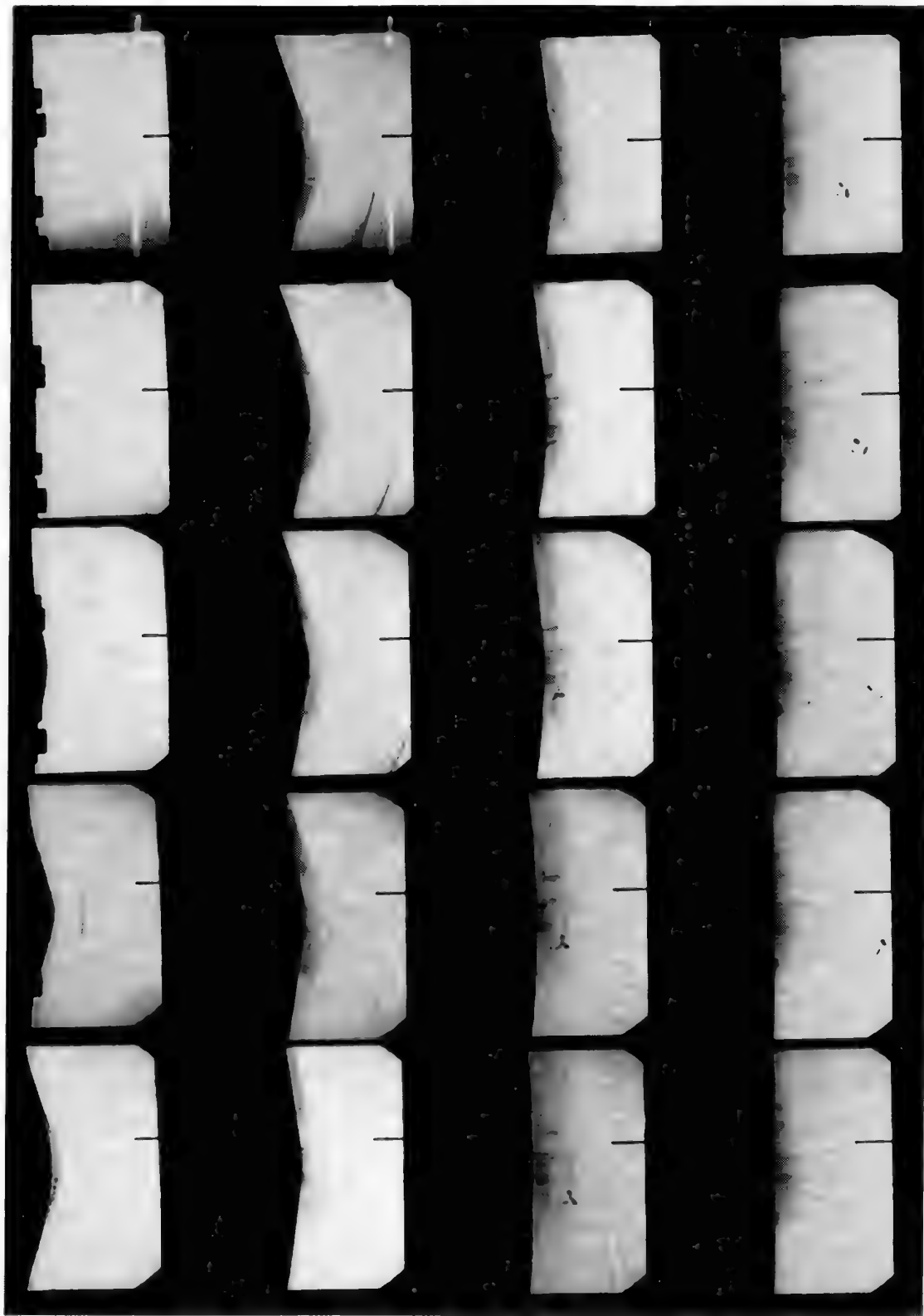Cer/GRP 24" x 24", total time 1950 μs

Figure 2.5   Shadowgraphs of Shot No. 10997, top view

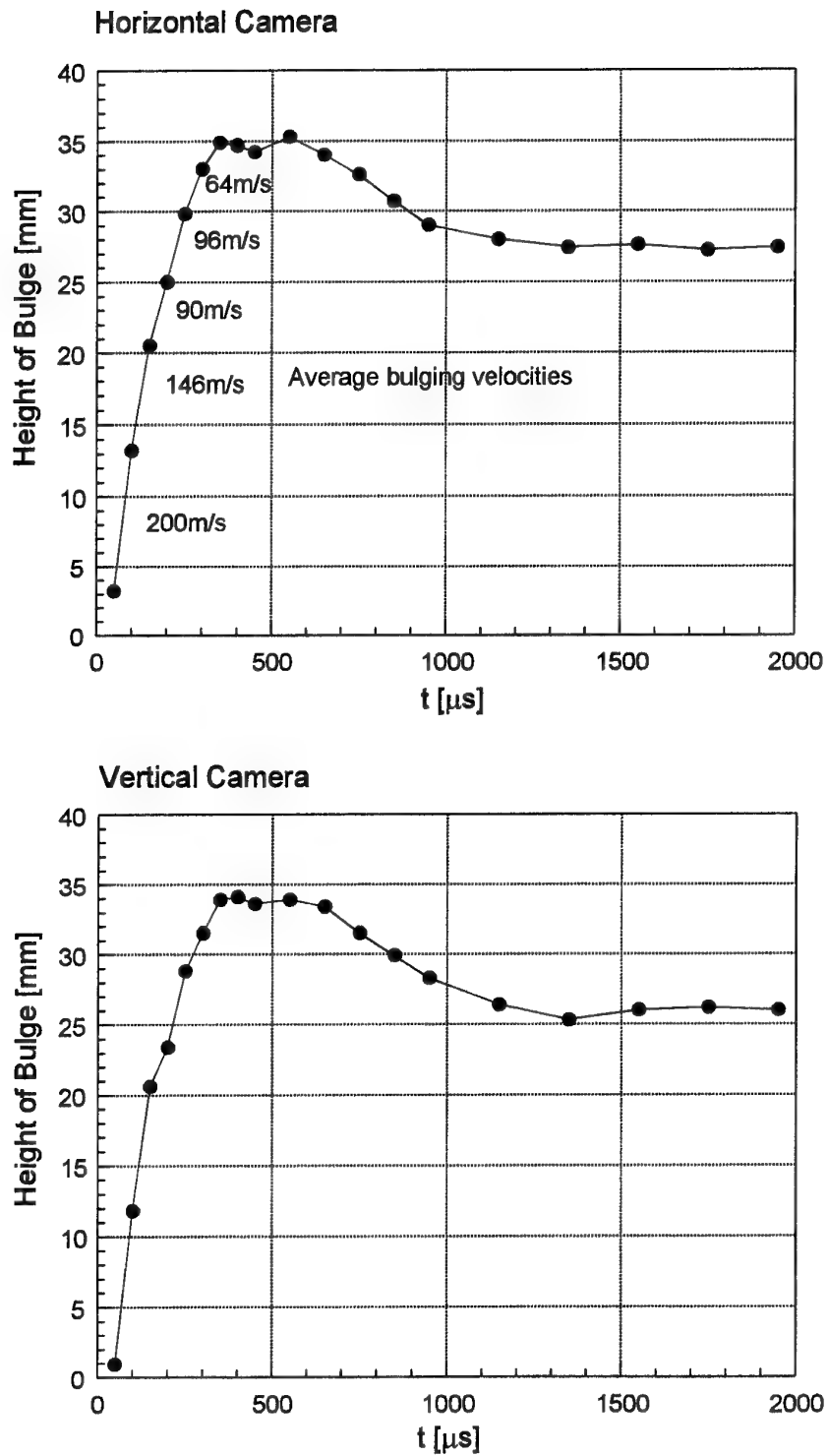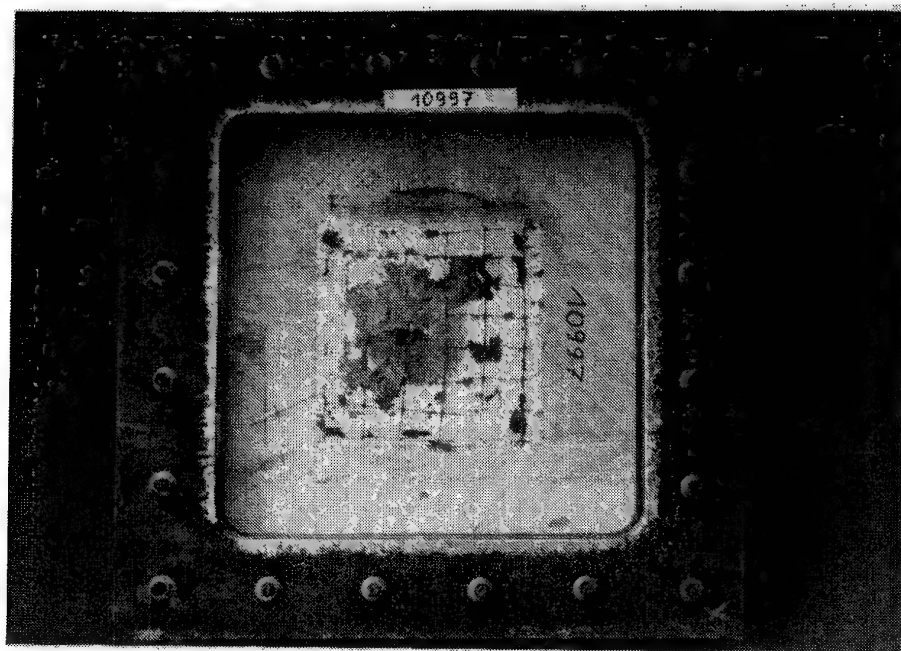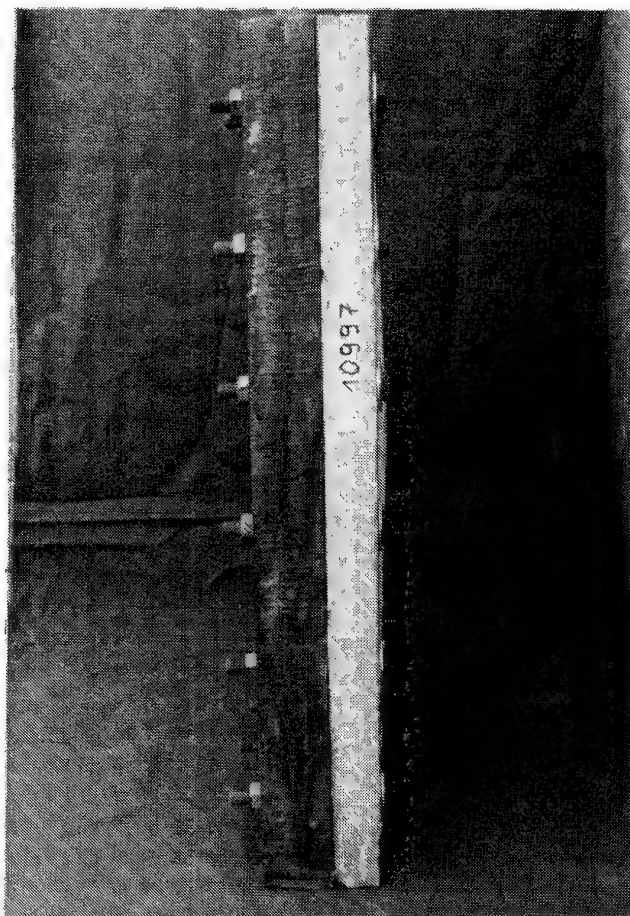## Horizontal Camera

Vertical Camera

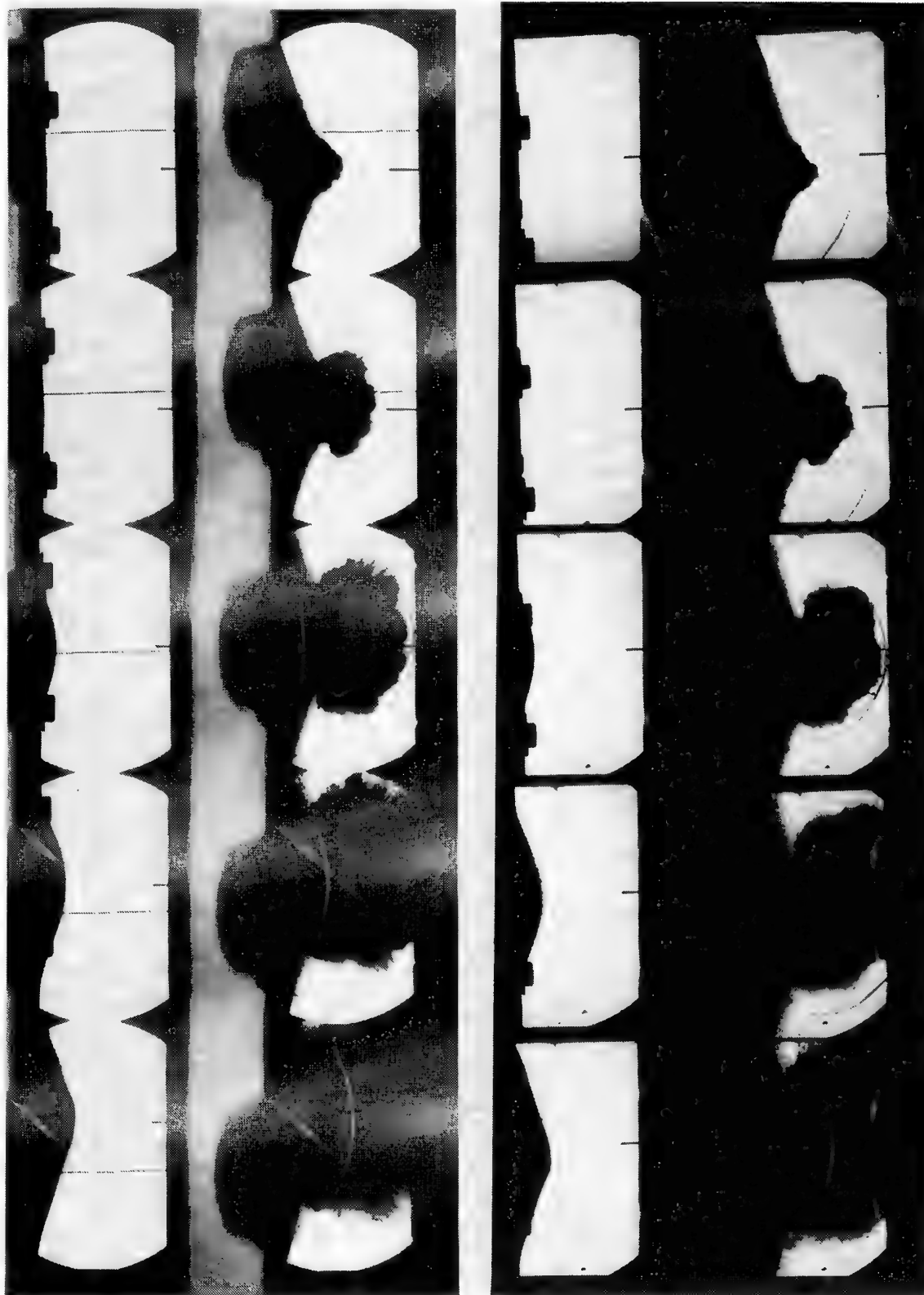Figure 2.6   Distance-time curves of Shot No. 10997

a)   Impacted side

b)   Side view, no delamination visible

Figure 2.7   Photographs of the impacted target, Shot No. 10997

Side view   Top view

Figure 2.8   Shadowgraphs of Shot No. 11000, v_P = 1091 m/s,
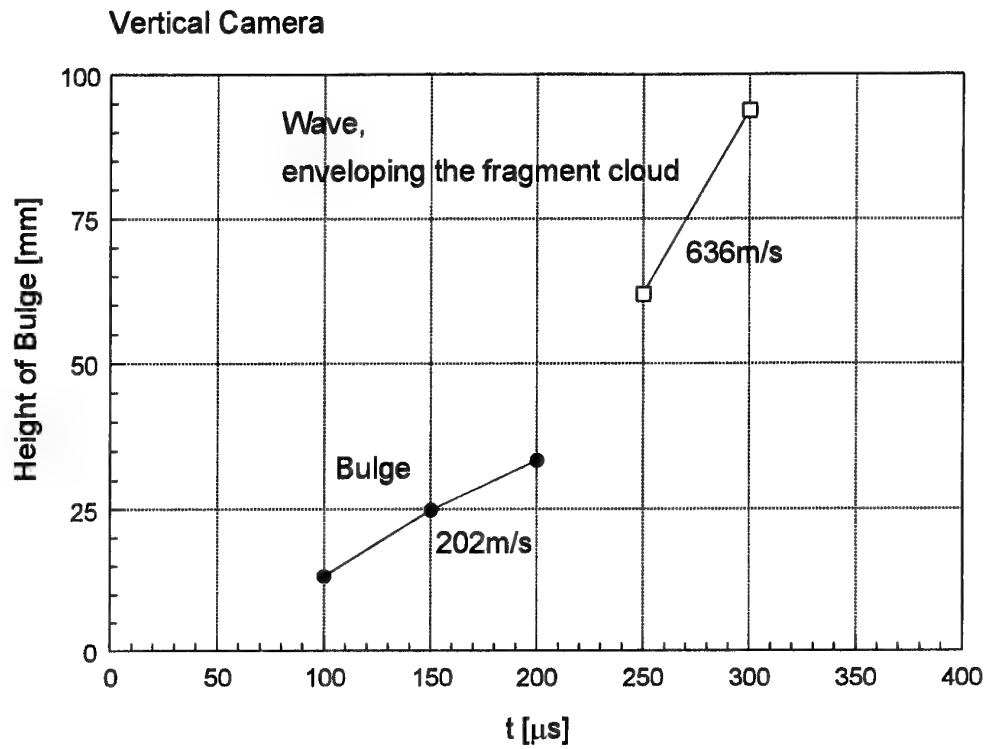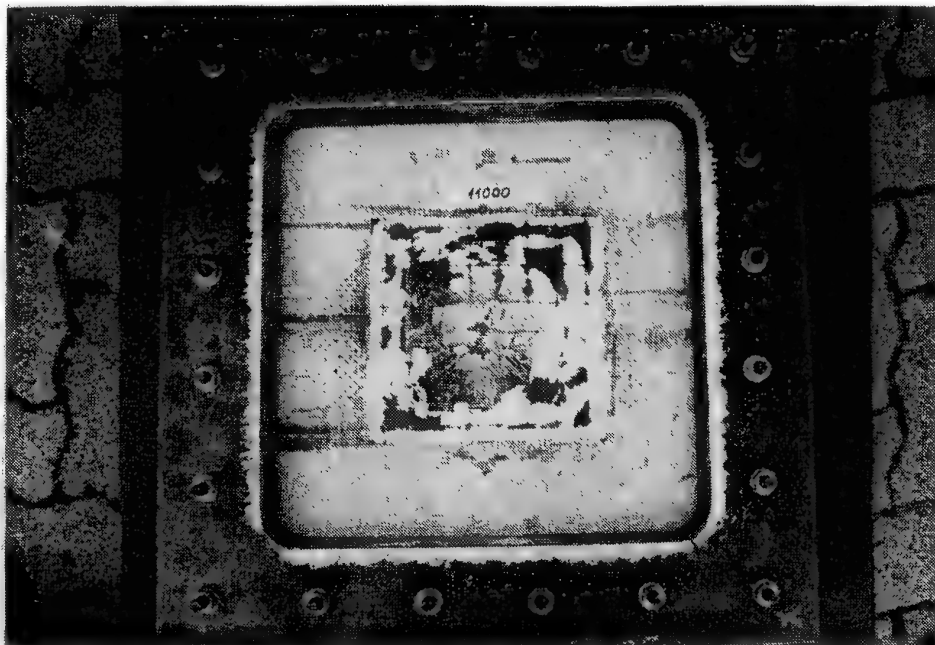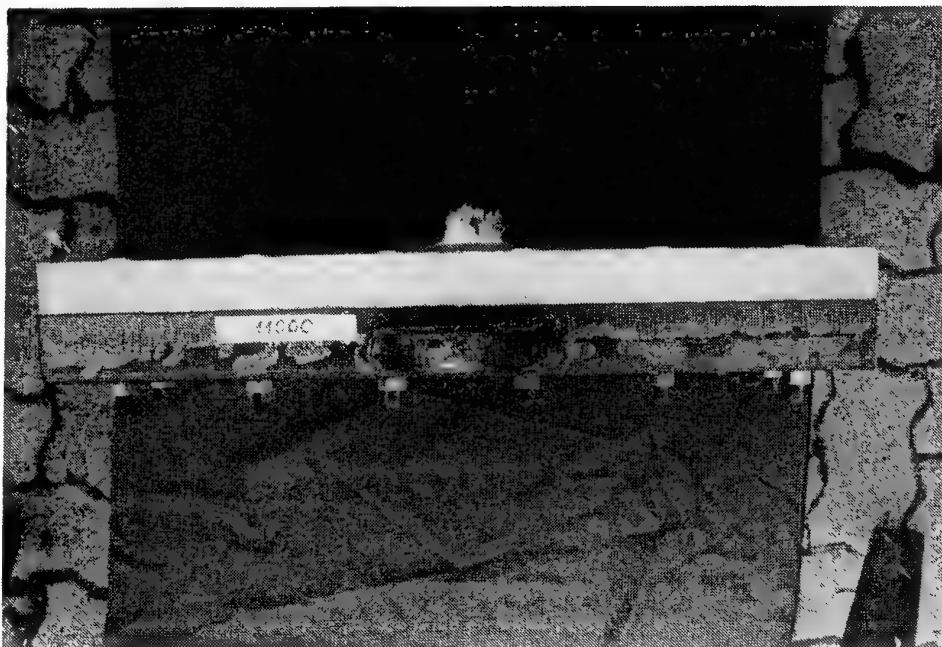Cer/GRP 24" x 24"

Vertical Camera

Figure 2.9   Distance-time curve of Shot No. 11000

a)   Impacted side

b)   Side view

Figure 2.10   Photographs of the impacted target, Shot No. 11000

Shot No. 10973

In the first shot against a 12" x 12" target the heads of the screws were also countersunk into the GRP. The shadowgraphs (Fig. 2.11) show a much stronger bulging in comparison to the 24" x 24" panels. The time intervals were 30 μs between the photographs 1 to 15 and 60 μs between the last photographs. A cloud of particles that have been detached from the rear of the small GRP panel can be recognized from picture no. 8. The contour of the cloud, which probably consists of epoxy particles, corresponds to the form of the bulge in an earlier stage.

From the distance-time curves (Fig. 2.12) it can be derived that the average bulging velocity is about 225 m/s during the first 200 μs and about 90 m/s afterwards. The particle cloud becomes visible approximately at the time when the decrease in the bulging velocity is observed. The inspection of the target revealed that four layers of the glass fiber were completely detached from the rear of the panel. The photographs of the target (Fig. 2.13) show a strong delamination of the GRP panel. Many layers are torn out at the screws or pulled over the washers, which were only slightly bigger than the screw heads.

Shot No. 10994

In the second experiment with a 12" x 12" target the bolts were not countersunk in order to guarantee that the GRP panel was completely fixed to the steel frame. The test was conducted at a striking velocity $v_P = 959$ m/s. Figure 2.14 shows the shadowgraphs which were taken in time intervals of 50 μs from picture no. 1 to no. 10, 75 μs from picture no. 10 to no. 15, and 100 μs between the last pictures. A strong bulging can be recognized which continues during the total time of observation (1325 μs). The distance-time plots displayed in Figure 2.15 show that the average velocity of the rear of the panel decreases from about 210 m/s to about 40 m/s after more than 1 millisecond. The photographs of the target (Figure 2.16) reveal that the GRP panel was also severely damaged by delamination in the rear half and that many layers were torn around the heads of the bolts. The projectile did not perforate the target. However, the result has to be regarded as target failure.
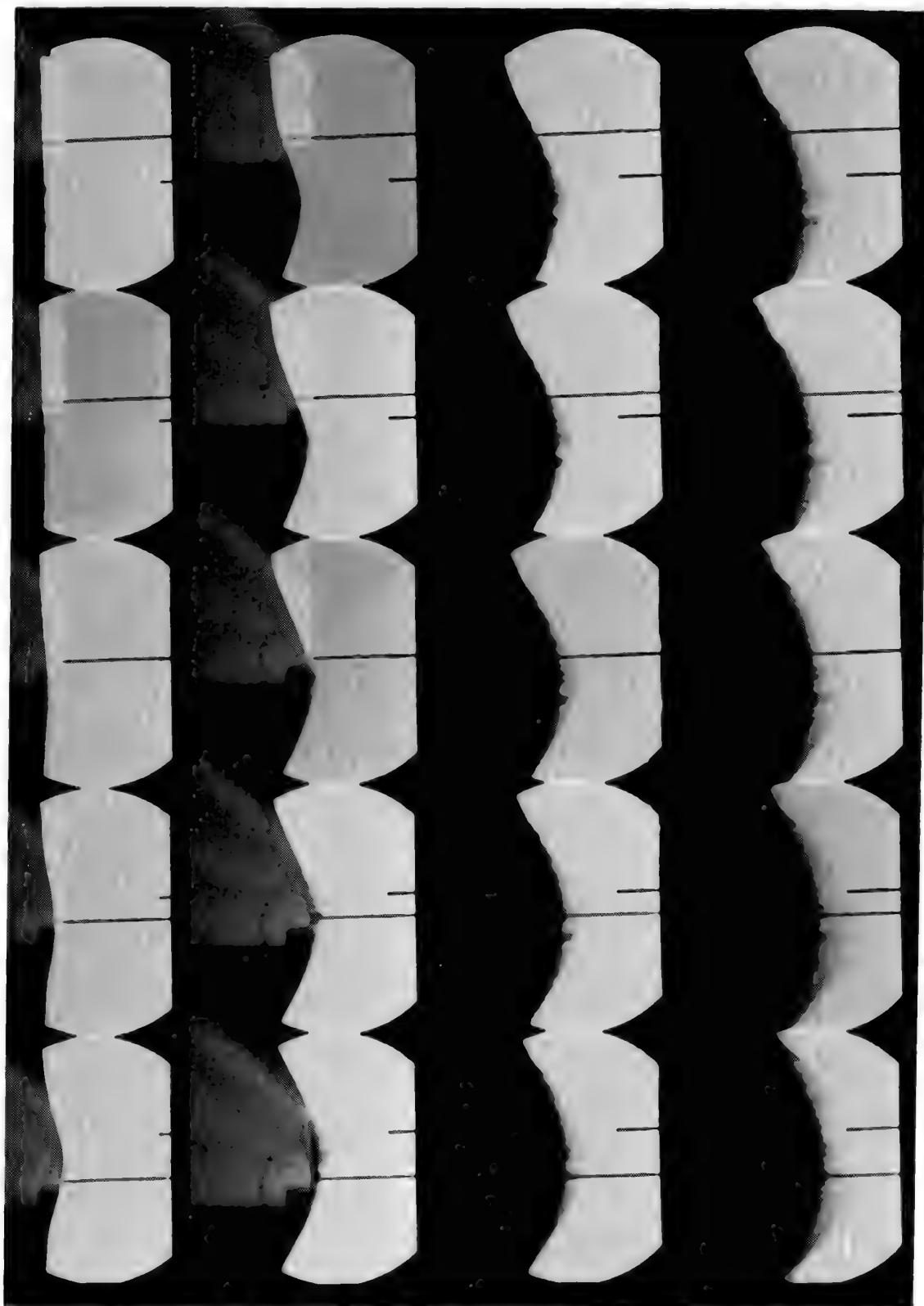
Figure 2.11   Shadowgraphs of Shot No. 10973, side view, v_P = 991 m/s,
Cer/GRP 12" x 12", total time - 730 μs
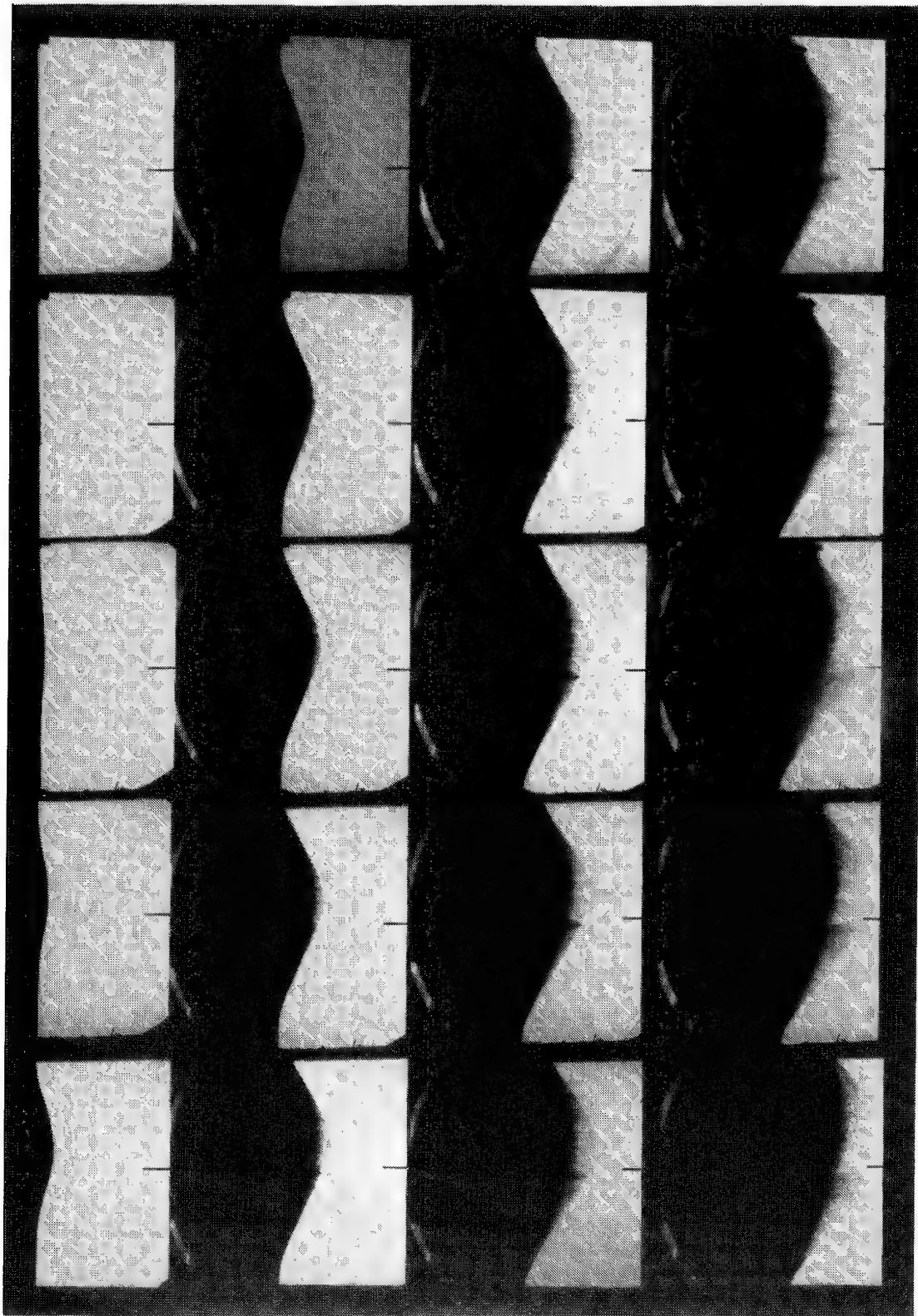
Figure 2.11 Shadowgraphs of Shot No. 10973, top view
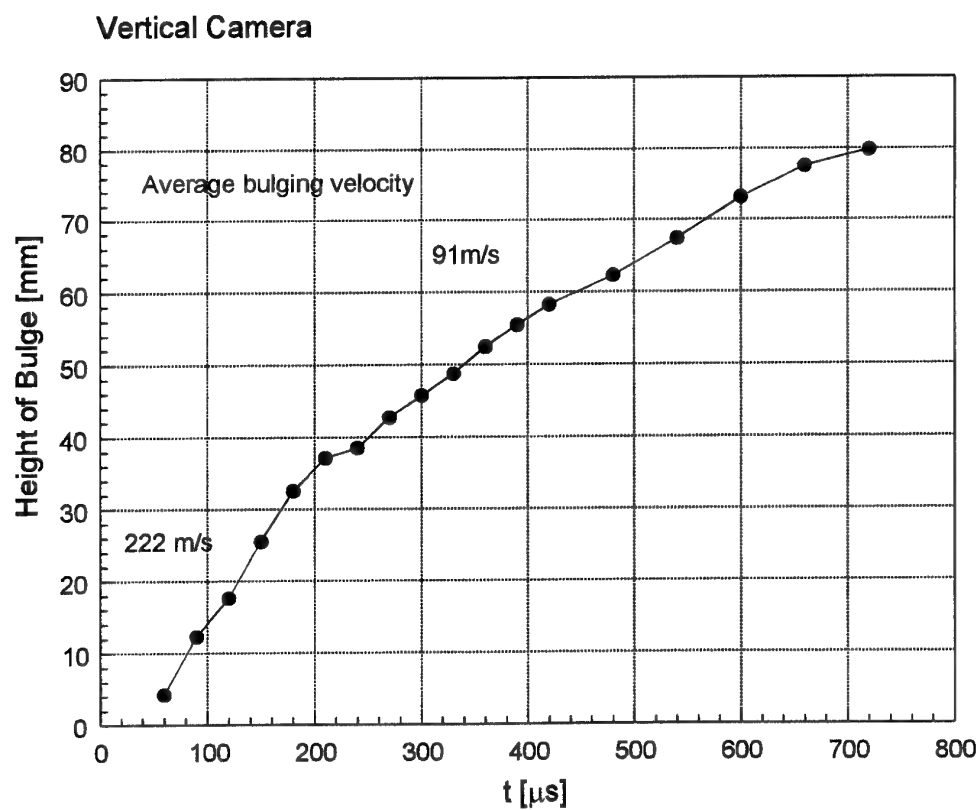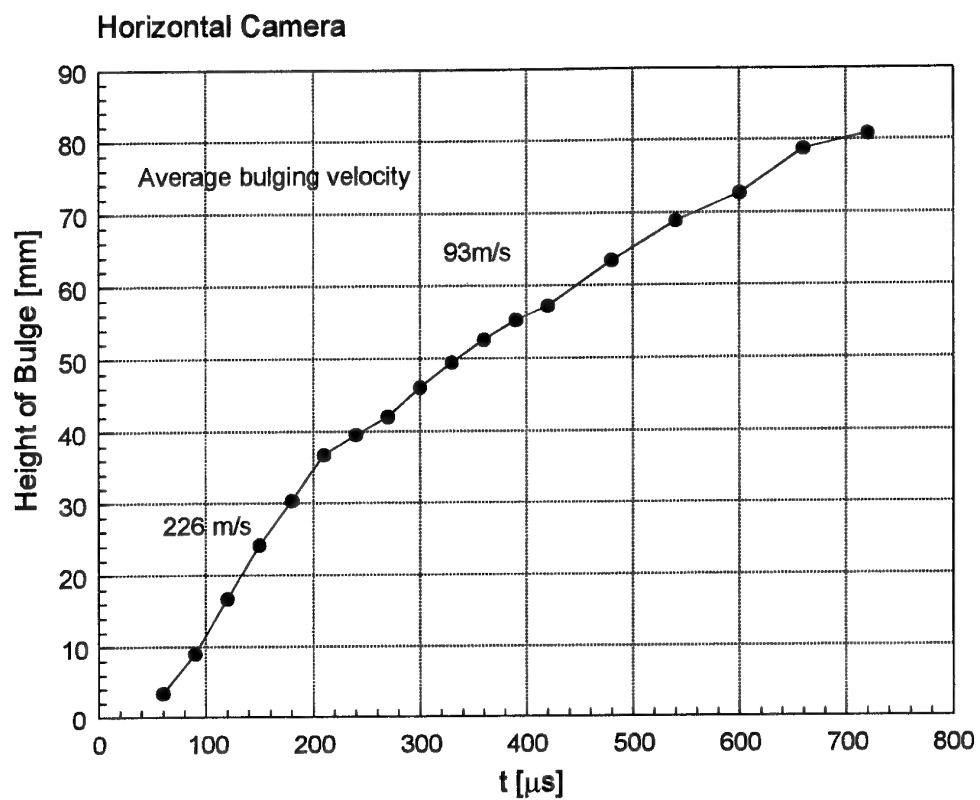
Horizontal Camera

Vertical Camera

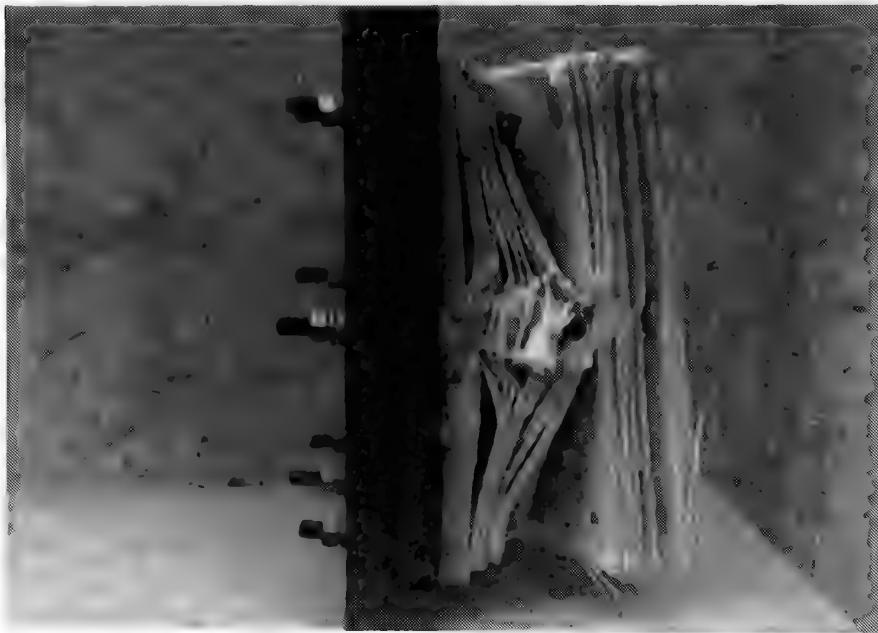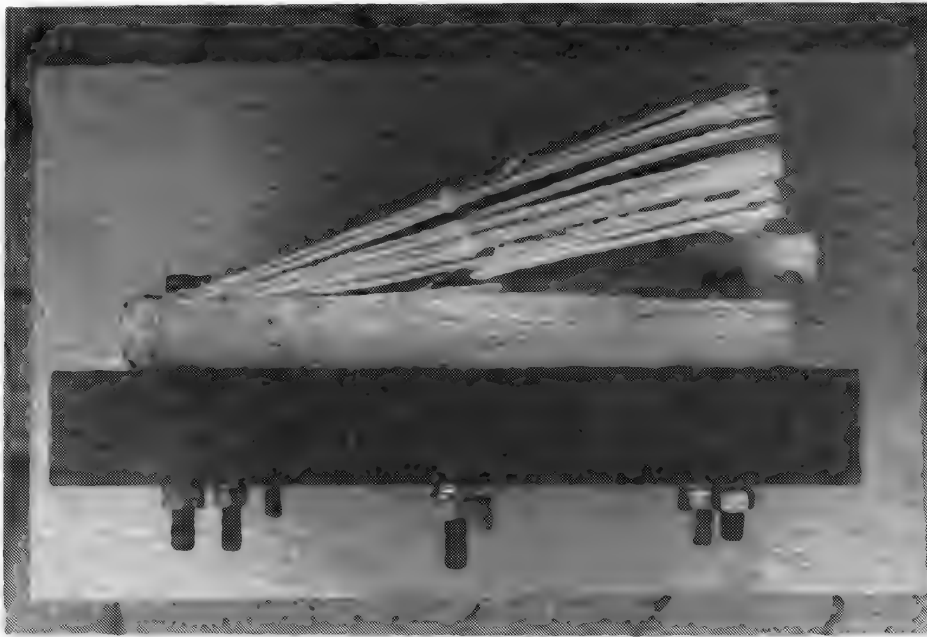Figure 2.12   Distance-time curves of Shot No. 10973

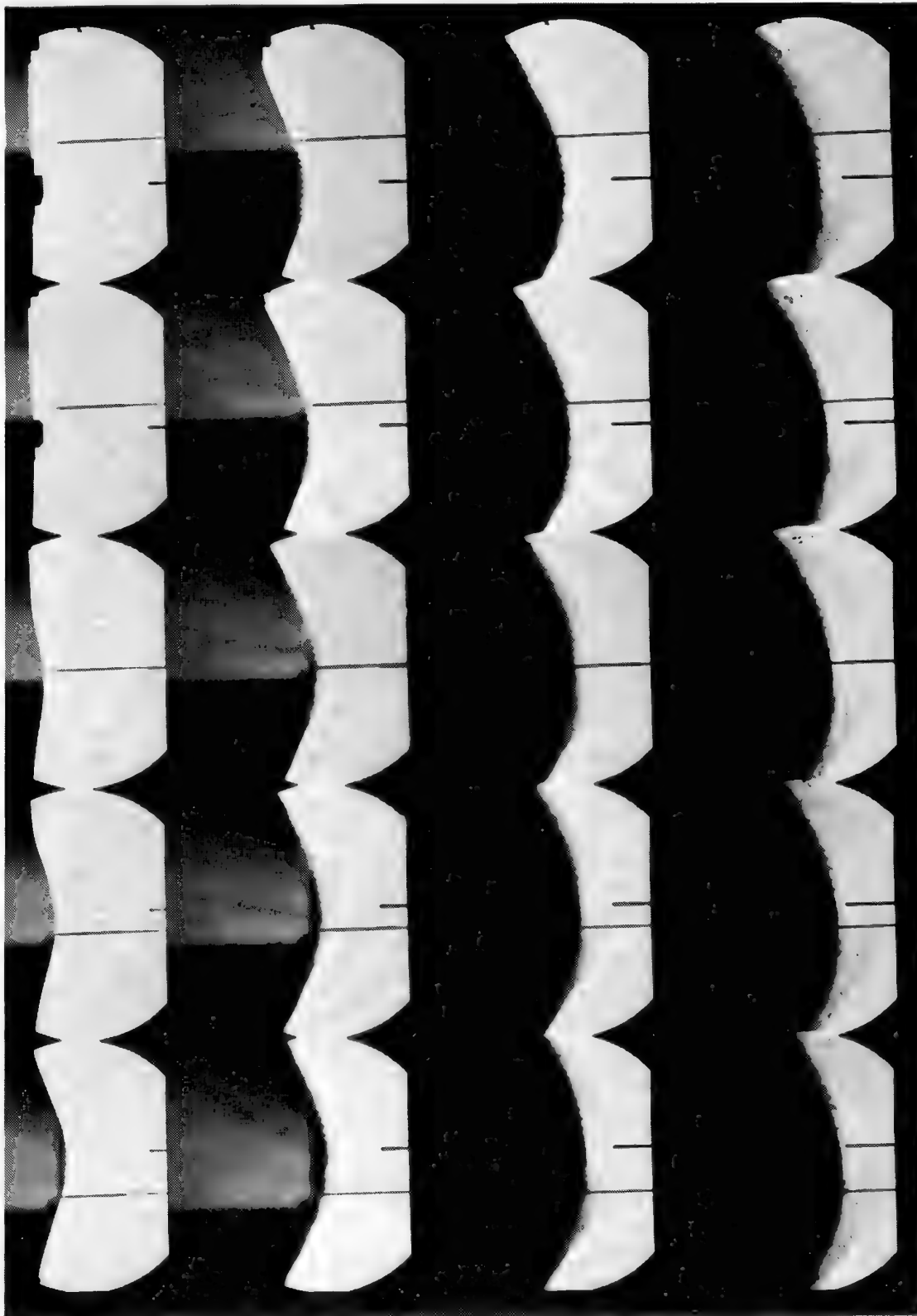Figure 2.13   Photographs of the impacted target, Shot No. 10973

Figure 2.14   Shadowgraphs of Shot No. 10994, side view, v_P = 959 m/s,
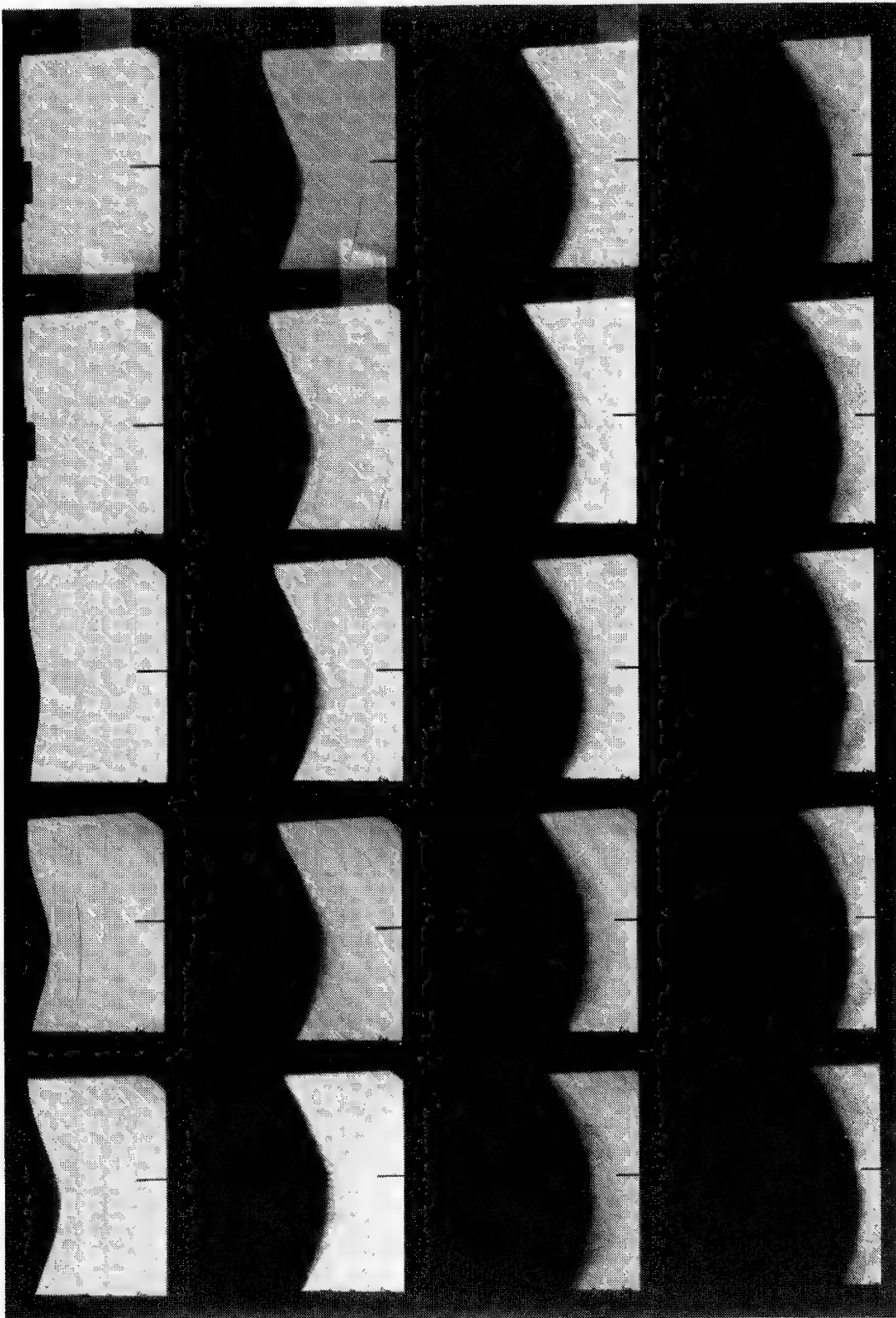Cer/GRP 12" x 12", total time 1325 μs

Figure 2.14   Shadowgraphs of Shot No. 10994, top view

Horizontal Camera

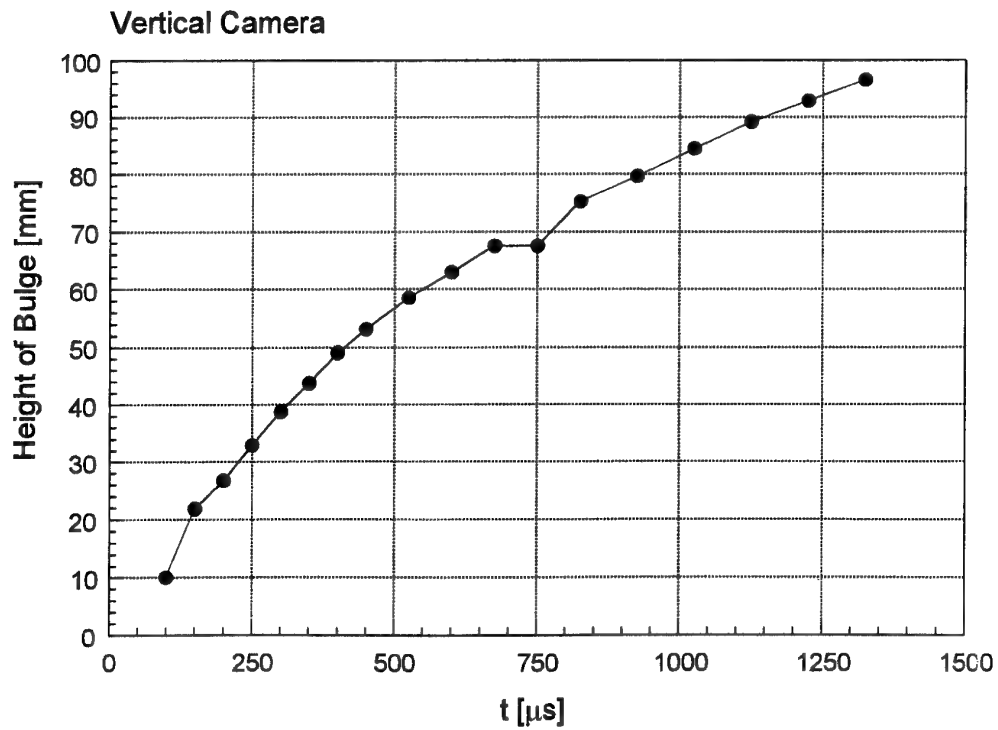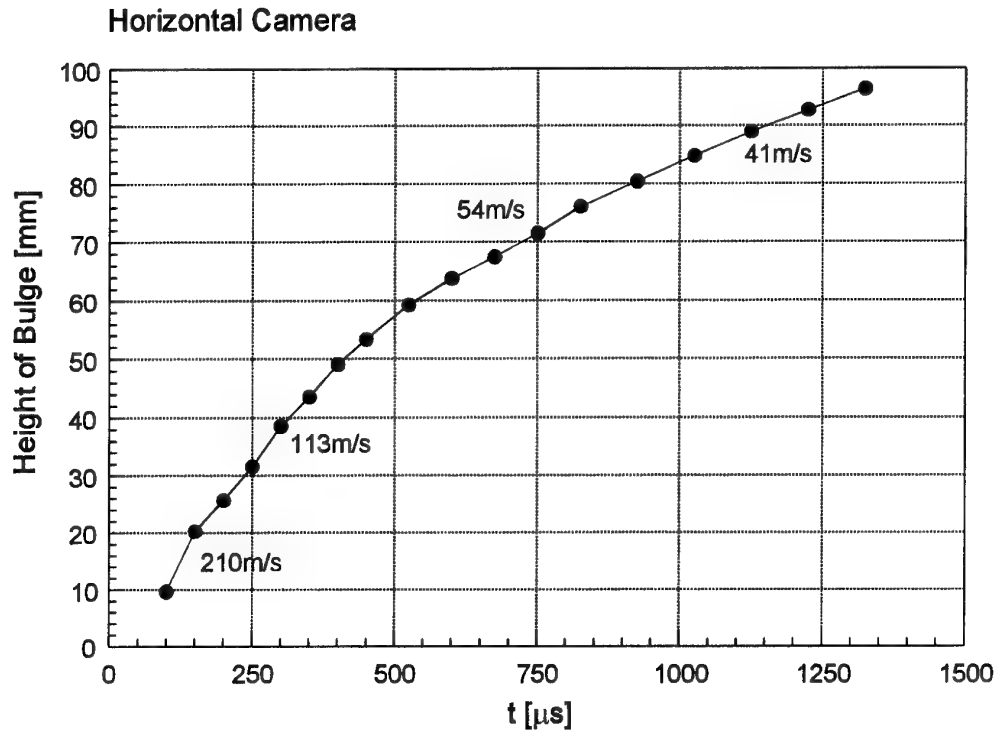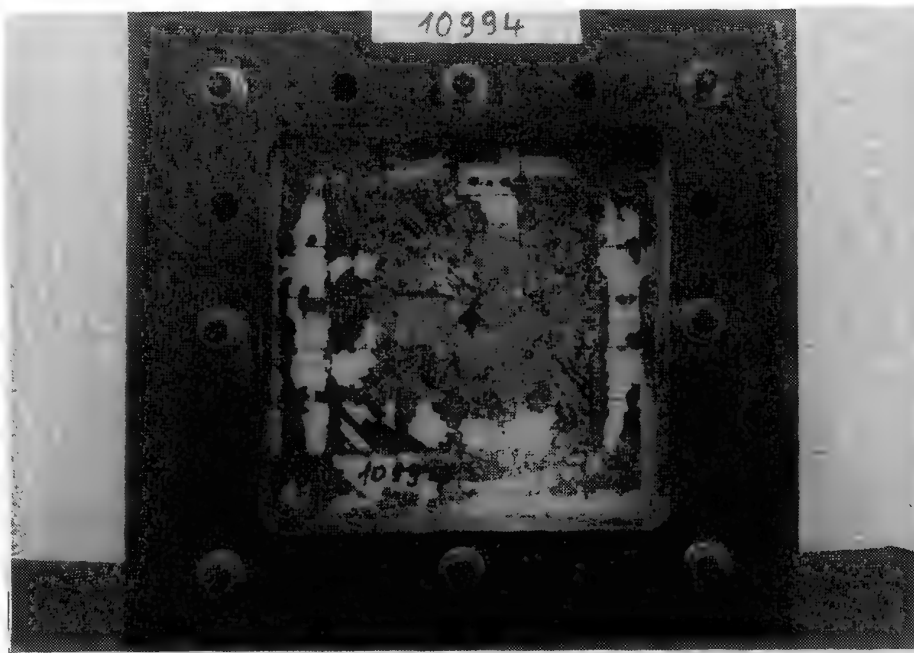## Vertical Camera

Figure 2.15   Distance-time curves of Shot No. 10994

a)   Impacted side

b)   Side view, showing the delamination

Figure 2.16   Photographs of the impacted target, Shot No. 10994

Shot No. 10998

In order to prevent GRP layers from being pulled over the nuts a steel frame of 10 mm thickness and 50 mm width was additionally clamped to the rear of the GRP panel. The test was conducted at v_P = 1001 m/s. From the shadowgraphs (Figure 2.17) it can be recognized that the projectile perforated the target. The time intervals between the first ten photographs were 50 μs. Perforation occurs between pictures no. 6 and 7, i. e. between 300 μs and 350 μs after impact. The bulge is only a few millimeters higher than in Shot No. 10994 at the time of the breakthrough of the projectile. Since no flash X-ray equipment was employed in this, test the residual velocity of the projectile could not be determined. Only an estimate of the expansion velocity of the debris cloud could be derived from the distance-time plots which are displayed in Figure 2.18. Photographs of the target are shown in Figure 2.19. The steel frame at the rear side of the GRP was also strongly deformed. The edges of the frame which were in contact with the GRP were rounded to prevent shear failure. The GRP did not fail at these sites. It is assumed that the possibility to absorb energy by elastic and plastic deformation of the GRP panel was reduced too much by the steel frame, which led to the perforation.

Shot No. 10999

In order to allow sufficient bending of the panel and to prevent GRP layers from being pulled over the nuts triangular shaped steel plate of 10 mm thickness were used instead of washers in the corners of the panel. Bigger washers were used at the central bolts. These modifications can be seen from the photographs of the target which are presented in Figure 2.22. The test was conducted at v_P = 997 m/s. The shadowgraphs in Figure 2.20 show that the maximum bulge height was reached during the time interval of observation. This can be seen more clearly from the distance-time plots shown in Figure 2.21. The maximum displacement of the panel was 102 mm and was reached at about 1350 μs after impact. The height of the residual static bulge is 54 mm. The photographs of Figure 2.22 show delamination and that GRP layers were also torn around three of the central screws in this test.
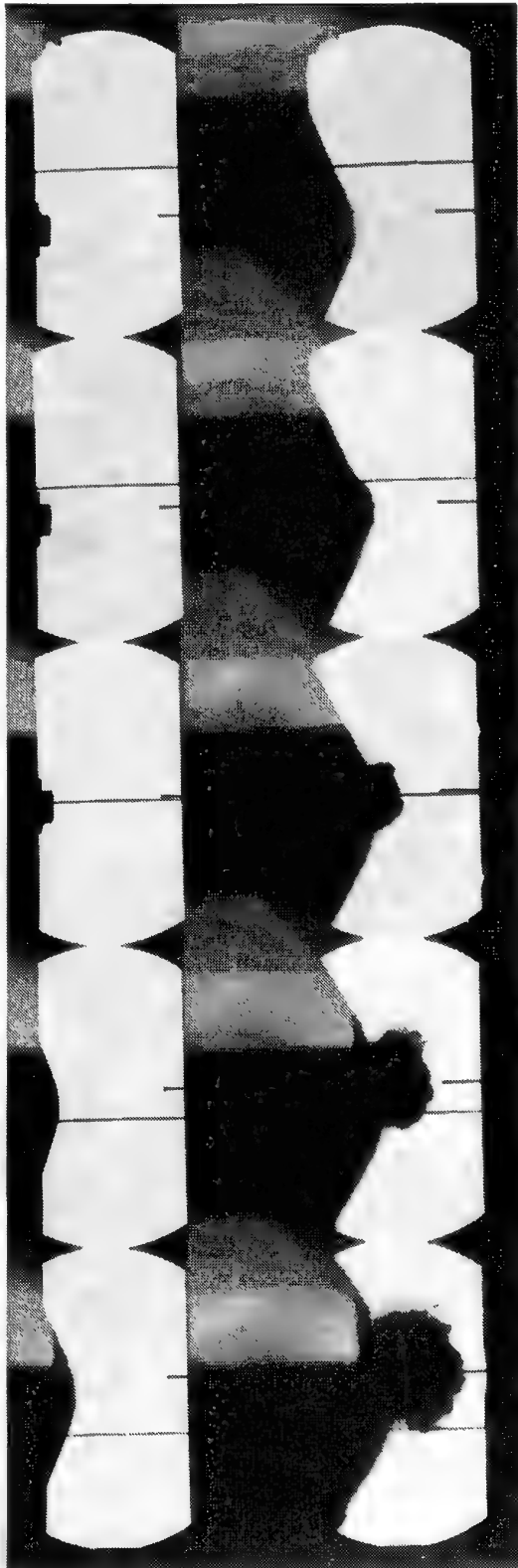
Side view   Top view

Figure 2.17   Shadowgraphs of Shot No. 10998, v_P = 1001 m/s,
               Cer/GRP 12" x 12"

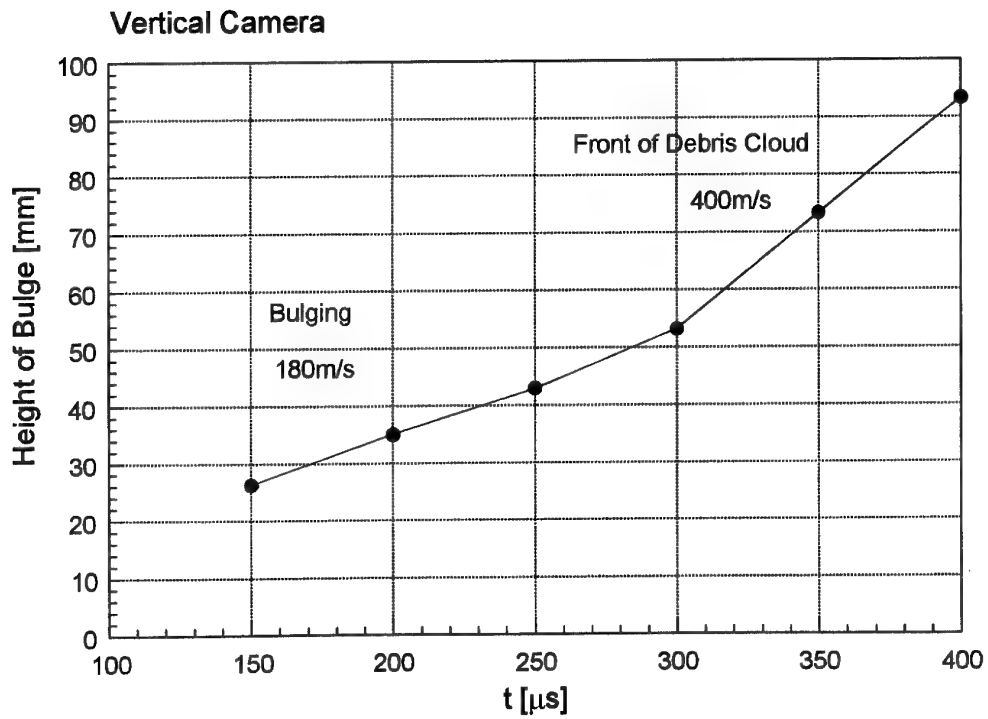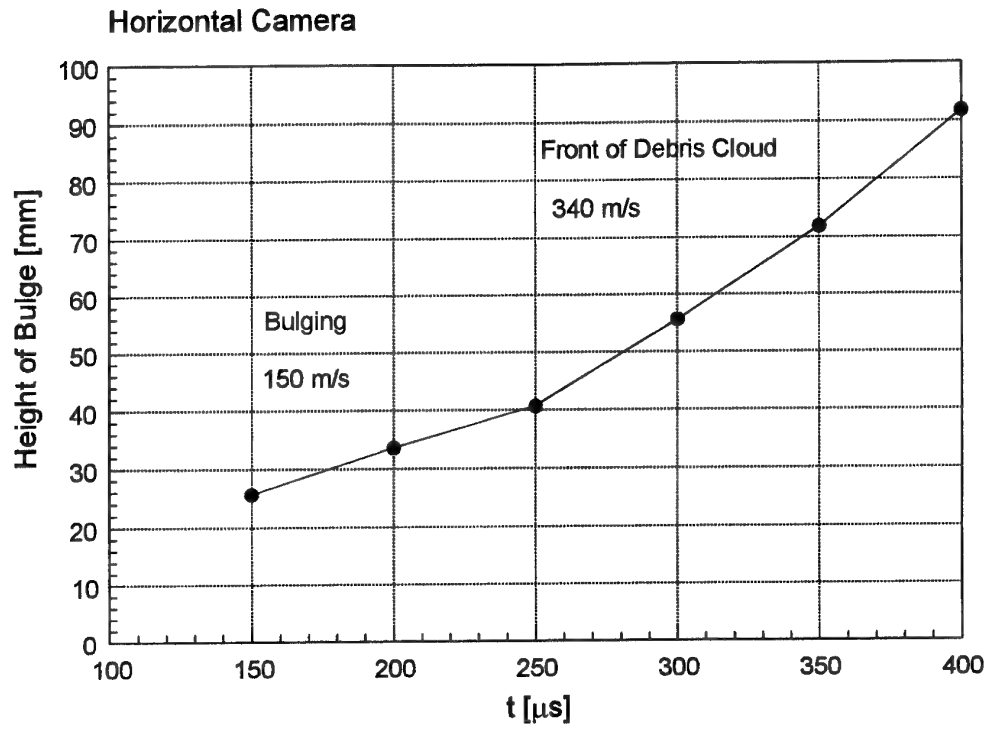## Horizontal Camera

Vertical Camera

Figure 2.18   Distance-time curves of Shot No. 10998
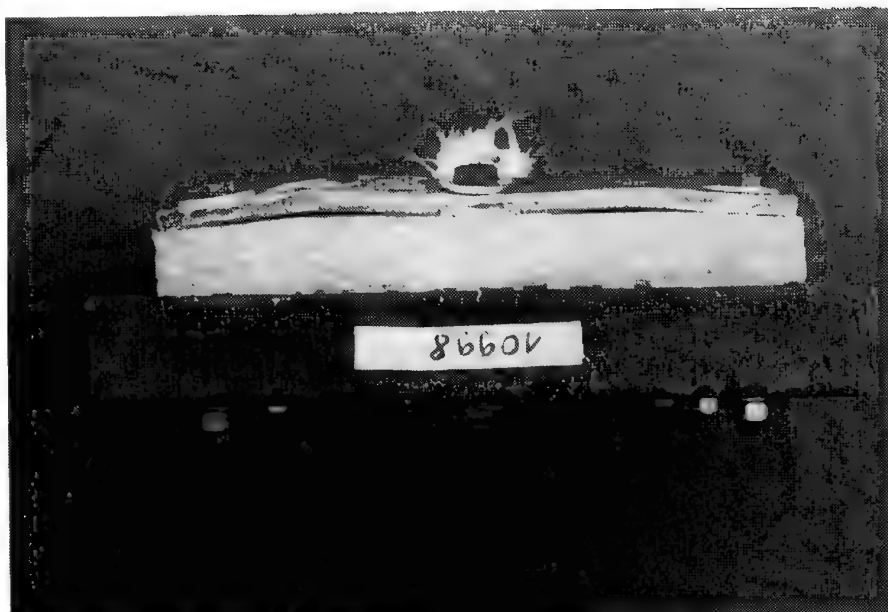
Figure 2.19   Photographs of the impacted target, Shot No. 10998
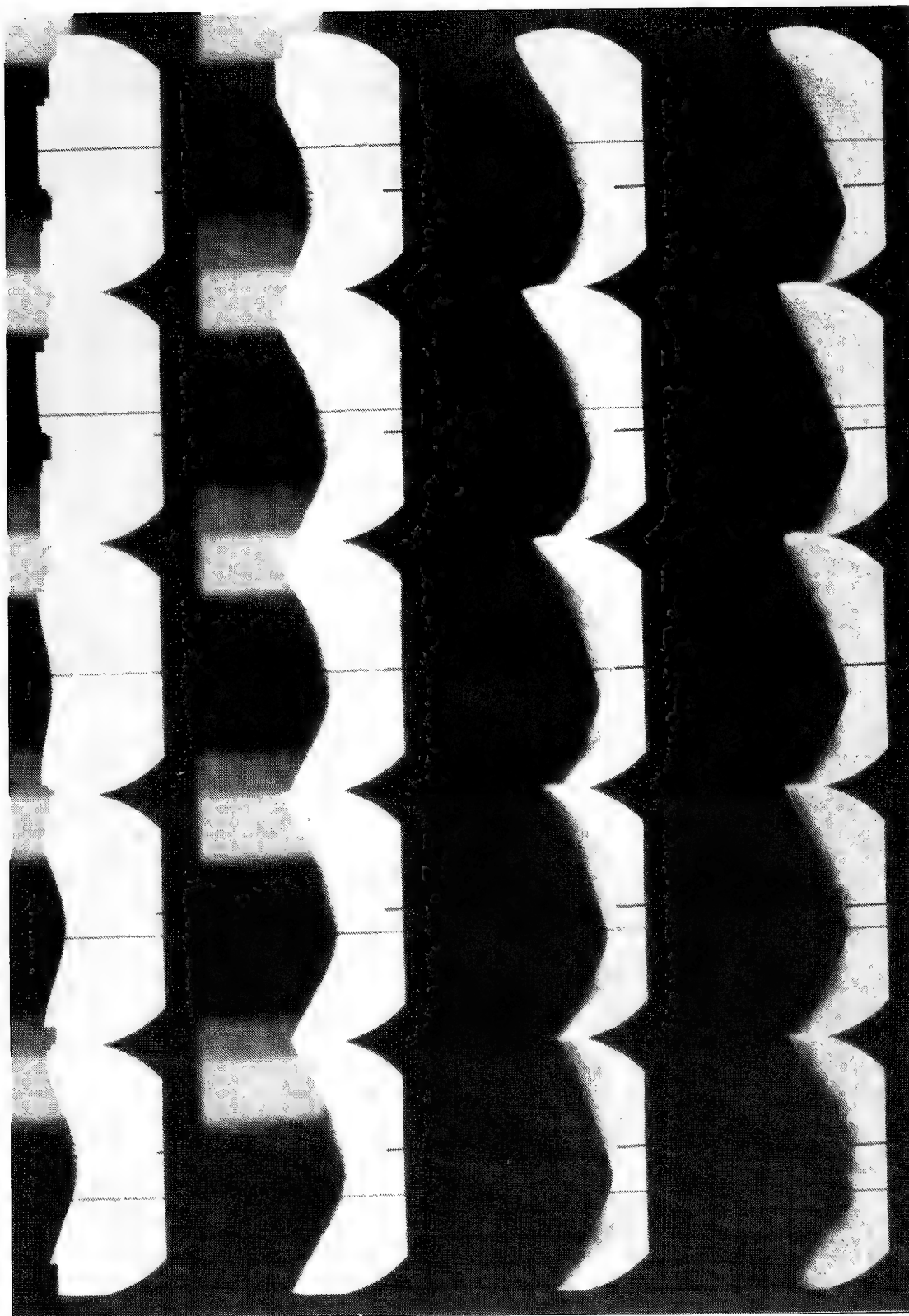
Figure 2.20 Shadowgraphs of Shot No. 10999, side view, v_P = 997 m/s, Cer/GRP 12" x 12", total time 1950 μs
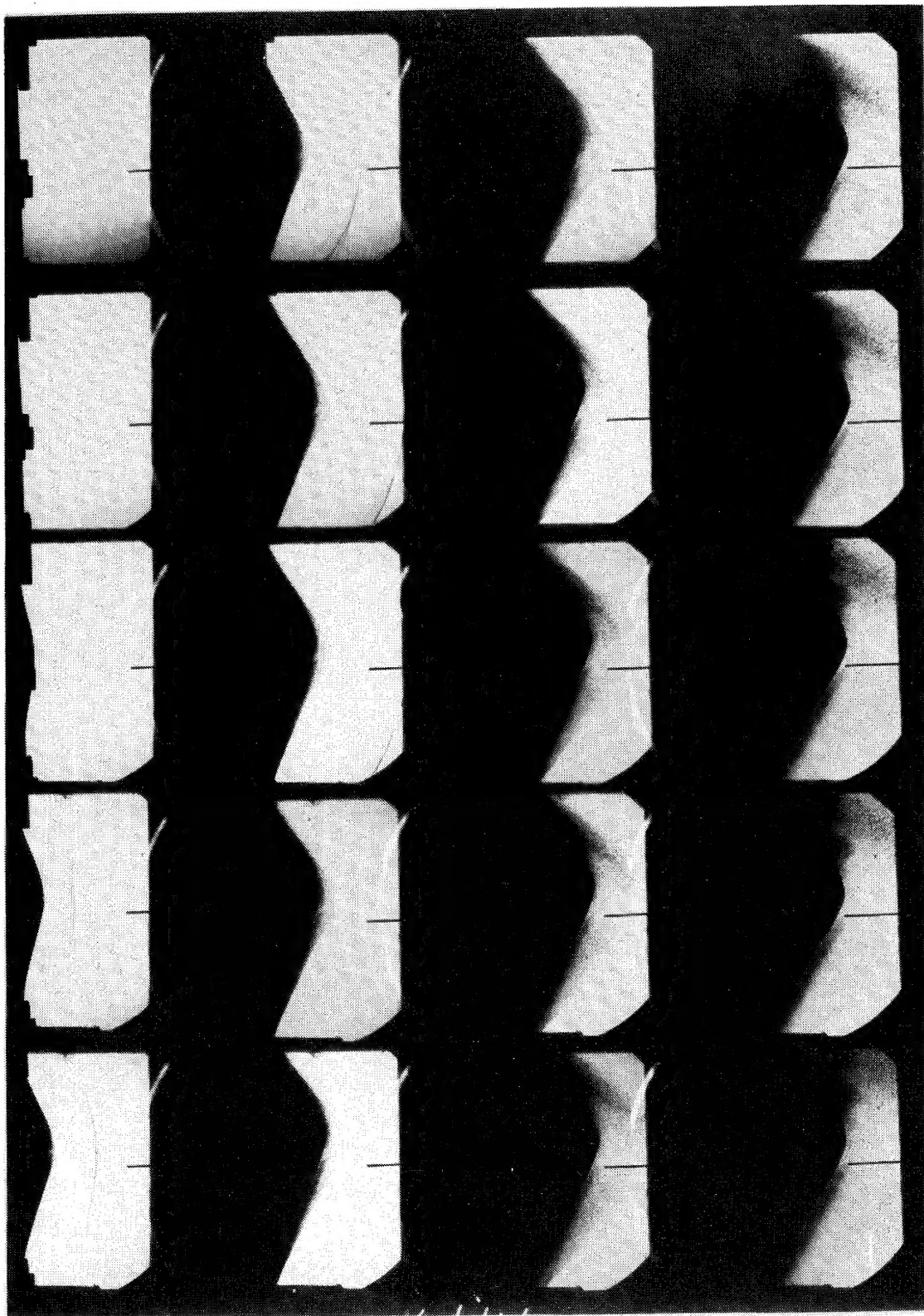
Figure 2.20   Shadowgraphs of Shot No. 10999, top view

Horizontal Camera
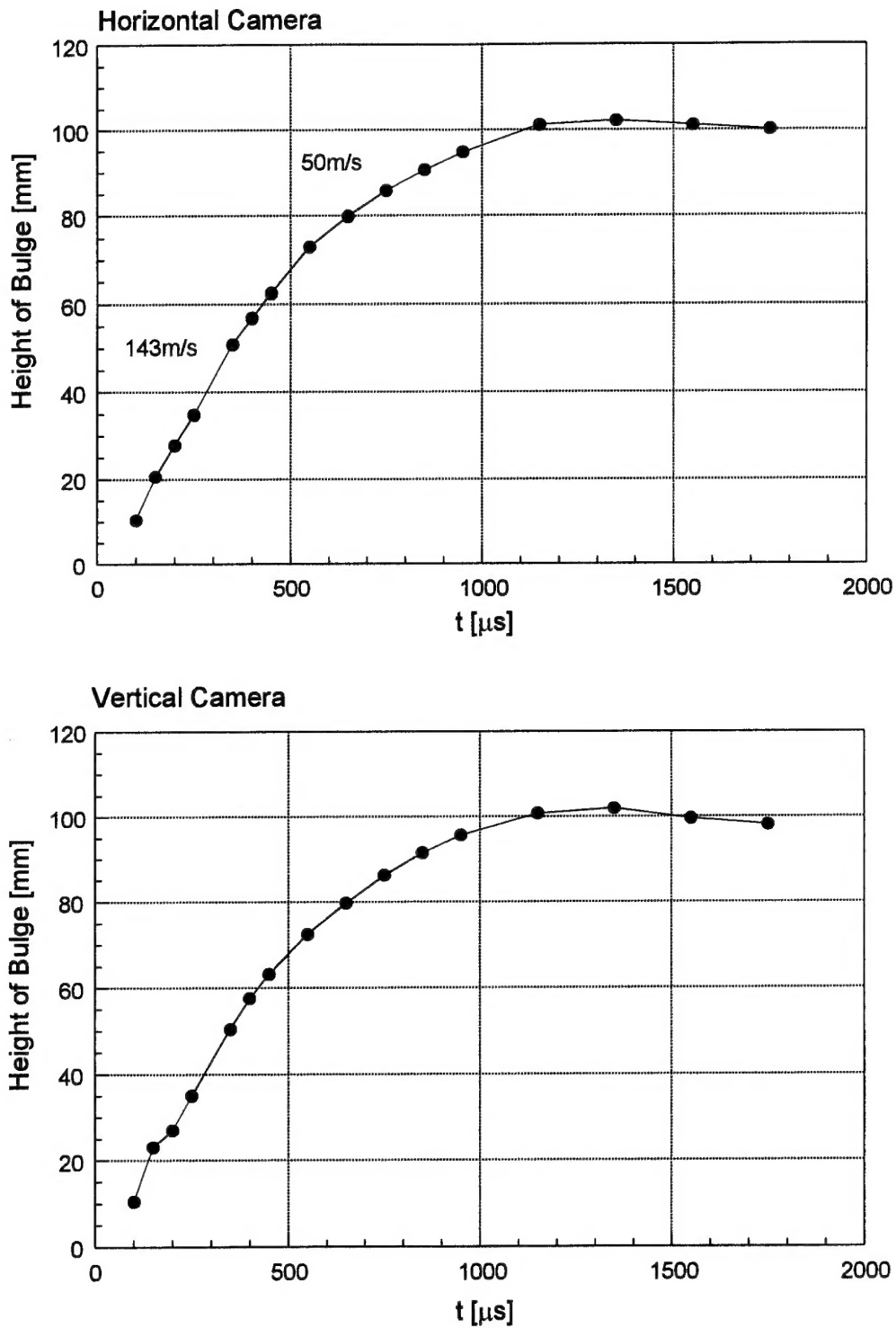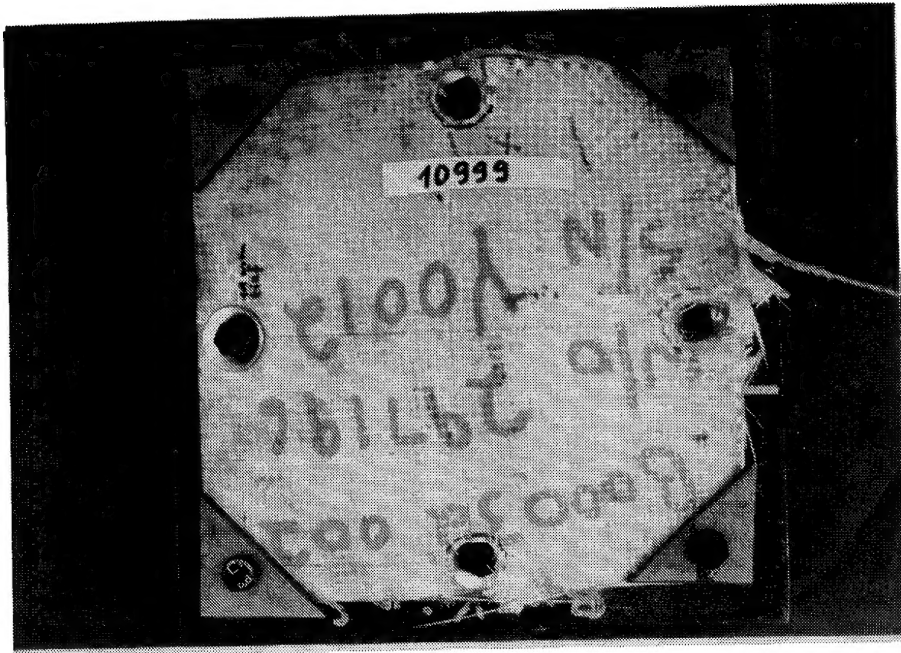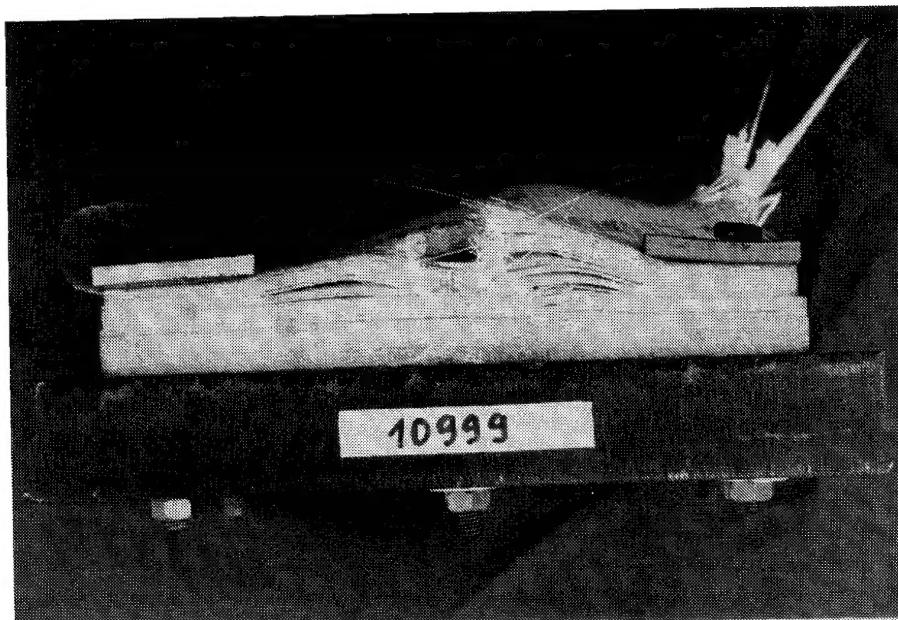

Vertical Camera

Figure 2.21   Distance-time curves of Shot No. 10999

a) Back side

b) Side view

Figure 2.22   Photographs of the impacted target, Shot No. 10999

3 Summary

Ceramic/GRP composites were impacted near their ballistic limit velocity with tungsten alloy projectiles. The bulging of the GRP panels was observed by means of two Cranz-Schardin cameras and the distance-time histories of the bulges were derived from the high-speed recordings.

In the case of targets with a GRP backing of the size 24" x 24" the projectile (v_P = 994 m/s) could be stopped without visible delamination of the GRP panel. The maximum height of the bulge was 35 mm and was observed between 300 μs and 400 μs after impact. The remaining static bulge had a height of 15 mm.

The 12" x 12" GRP panels exhibited a much stronger deformation. The bulge reached a height of about 100 mm after 1.35 ms and a static bulge of 54 mm height remained. Delamination of the GRP panel could not be prevented and part of the layers were torn around the bolts that fixed the target.

A bulging of the GRP panels could be recognized for both the 12" square panels and the 24" square panels not before $\approx$ 50 μs after impact and the maximum bulge heights were observed between 300 μs and 400 μs after impact. The simple hydrodynamic description of the penetration into the ceramics yields a penetration velocity U $\approx$ 680 m/s in the case of an impact velocity v_P = 1000 m/s. From this estimation follows a total time of 59 μs for the projectile to penetrate the ceramics. That means that at the time when the bulge begins to form the projectile has already penetrated most part of the ceramics and is strongly eroded. The bulging appears therefore to be primarily caused by the residual projectile. This means that the ceramic tiles are supported by the GRP during penetration for both sizes of the panels. However, the 24" panels can absorb more energy by elastic and plastic deformation and exhibit therefore much less damage after having been impacted.

Acknowledgement